Faculty of Electrical Engineering

DUTY CYCLE PREDICTION CONTROL TECHNIQUE FOR A DC-DC BUCK CONVERTER BASED ON DOMINANT POLES LOCATION

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Bachelor of Electrical Engineering (Control, Instrumentation & Automation)

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DECLARATION

I hereby, declared this report entitled "Duty Cycle Prediction Control Technique for A Dc-Dc Buck Converter Based on Dominant Poles Location" is the result of my own research except as cited in references.

Signature : ……………………………………

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Date : 30 MAY 2017

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in term of scope and qualify for the award of the degree of Bachelor of Electrical Engineering (Control, Instrumentation and Automation).

Signature : ....

Name of Supervisor : ....

Date : ....

ABSTRACT

The DC-DC converter is designed by controlling the input voltage using switch mode configuration to obtain a desired DC output voltage. DC-DC converter are divided into three types which are buck converter, boost converter and buck-boost converter. A feedback control strategy is needed to accomplish the DC-DC converter system to produce good transient response and zero steady-state error. The objective of this project is to do system modelling on DC-DC buck converter. Since the aim of this project is to achieve good transient response and zero steady-state error, a feedback controller which is modified PID controller is formulated in order to predict a duty cycle for DC-DC buck converter which called as Duty Cycle Prediction Control Technique. Finally, to analyse the transient response and steady-state error of the DC-DC buck converter. There are two methods to work on system with and without controller and for duty cycle prediction. The first method is by modeling the system and second method is by using real plant. For the first method, the modeling on DC-DC buck converter has been done to obtain the transfer function of plant system. The step response and root locus of the system with and without controller has been obtained by using coding in the MATLAB. Meanwhile, good transient response and zero steady-state error by Duty Cycle Prediction Control Technique has been verified by using MATLAB/Simulink. For the second method, there are three cases have been tested which were changes in reference voltage, load and input voltage on system with and without controller. A modified PID controller has been designed and constructed. The derivative time, derivative gain and gain value has been obtained by using root locus technique. The algorithm used in the duty cycle prediction has been derived by using the partial fraction method based on the dominant poles location. Eventually, the modified PID controller has been inserted into the system with controller and duty cycle prediction. From the result, the proposed idea, Duty Cycle Prediction Control Technique has been successfully perform the case change in reference voltage. It produced good transient response and zero steady-state error. Therefore this technique can be used as the new feedback control technique.

ABSTRAK

Penukar DC-DC direka dengan mengawal voltan input yang menggunakan konfigurasi suis mod untuk mendapatkan DC voltan output yang dikehendaki. Penukar DC-DC dibahagikan kepada tiga jenis iaitu penukar buck, penukar rangsangan dan penukar buck-boost. Satu strategi kawalan maklum balas yang diperlukan untuk mencapai sistem penukar DC-DC untuk menghasilkan sambutan fana baik dan kesilapan sifar keadaan mantap. Objektif projek ini adalah untuk membuat sistem model penukar DC-DC buck. Untuk mencapai sambutan fana baik dan kesilapan sifar keadaan mantap, pengawal maklum balas yang pengawal PID yang diubah suai dirumus untuk meramalkan kitar tugas untuk penukar DC-DC buck yang dipanggil sebagai Teknik Ramalan Duty Cycle. Akhir sekali, untuk menganalisis sambutan fana dan ralat kesilapan mantap penukar DC-DC buck. Terdapat dua kaedah untuk sistem dengan dan tanpa pengawal dan untuk ramalan prediction. Cara pertama adalah mengguanakan sistem model. Cara kedua adalah menggunakan sistem sebenar. Bagi kaedah pertama, pemodelan pada penukar DC-DC buck telah dijalankan bagi mendapatkan fungsi pindah sistem sebenar. Sementara itu, sambutan fana dan ralat kesilapan mantap oleh Teknik Ramalan Duty Cycle telah disahkan dengan menggunakan MATLAB / Simulink. Bagi kaedah kedua, terdapat tiga kes telah diuji iaitu perubahan dalam voltan rujukan, beban dan voltan input pada sistem dengan dan tanpa pengawal. Sebuah pengawal PID diubahsuai telah direka dan dibina. Masa terbitan, keuntungan derivatif dan nilai keuntungan telah ditetapkan berdasarkan cara londar punca. Algoritma yang digunakan dalam ramalan kitar tugas telah diperolehi dengan menggunakan pecahan separa. Akhirnya, pengawal PID yang diubah suai telah dimasukkan ke dalam sistem dengan ramalan pengawal dan duti kitaran. Dari keputusan itu, idea yang dicadangkan, Teknik Ramalan Duty Cycle telah berjaya melaksanakan perubahan berlaku di voltan rujukan. Ia menghasilkan sambutan fana baik dan sifar keadaan mantap. Oleh itu, Teknik Ramalan Duty Cycle boleh digunakan sebagai teknik kawalan maklum balas yang baru.

DEDICATION

Dedicated to

my beloved father, Lau Ah Peng

my appreciated sibling, Lau Khai Shian and Karen Lau

my special friend Ng Tiew Lye for giving me moral support, cooperation, encouragement and also understanding

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CHAPTER 1

INTRODUCTION

1.1 Introduction

DC-to-DC converter is an electronic circuit and it is able to convert direct current (DC) source from one voltage level to another. It is one of a type of electric power converter. The DC-DC converter is designed by controlling the input voltage using switch mode configuration to obtain a desired DC output voltage. One of the applications of DC-DC converter is found in batteries charging system. For instance, if there is no voltage control when a battery discharge will cause the battery decreases and may come out with a lot of problems. The most efficient way of regulating voltage is using a DC-DC converter.

DC-DC converter are divided into three types which are buck converter, boost converter and buck-boost converter. Basically the buck and boost types converter are used to increase or decrease the output voltage lower or higher that the input voltage, respectively. For a wider usage, buck-boost converter is introduced to function either as buck or boost converter. Buck converter is also called as step-down converter to step down input voltage to its output voltage. While boost converter is called as step-up converter which step up its input voltage to its output voltage.

A feedback control strategy is needed to accomplish the DC-DC converter system. Without a feedback control strategy, a steady-state error occurs at DC output voltage for the case step-change of load or voltage output. The most recognised control strategy is Proportional-Integral-Derivative (PID) and modified PID controller.

In this final year project, Duty Cycle Prediction Control Technique has been developed to obtain a controllable DC output voltage. MATLAB/Simulink is used to simulate it so that it can achieve a good transient response and zero steady-state error of DC output voltage. It has tested for transient case with changes in reference voltage.

1.2 Motivation

The function of DC-DC buck converter is to step down the input voltage to its output voltage. A modified PID controller has been designed to ensure a better output response and desired output voltage based on the requirement. In power electronics field, the DC-DC buck converter is preferably used because of its simplicity, low cost and high efficiency. DC-DC buck converter is always efficient (which often higher than 90%), it is useful for tasks like converting a computer's main large of the supply voltage (normally 12V) to lower voltages or reference voltages that needed by USB, RAM or CPU. Eventually the buck converter should be accomplished by controller to achieve better performance and the controller used is modified PID controller. Duty Cycle Prediction Control Technique is developed because it is simple and more autonomous.

1.3 Problem Statement

The buck converter should be accomplish by controller to regulate the voltage. Without a feedback control strategy, a steady-state error occurs at DC output voltage for the case change of load or voltage output.

Proportional-integral-derivative (PID) controller is always used in a lot of closed-loop control system. By tuning the parameters of PID controller for example proportional gain which is Kp, integral gain which is Ki and derivative gain which is Kd, linear or non-linear system can achieve satisfied performance. Practically, a normal PID control system will produce a set-point kick phenomenon [15]. Set-point kick phenomenon is somehow like the output signal come out with sharp points and this make the output signal is not smooth enough.

To overcome this problem, a modified PID is used. Basically, it can prevent the set-point kick phenomenon, this is because instead of putting PI-D or I-D and the derivative action in the forward path, it will be placed in a smaller loop around the plant. However, the modified PID is more complicated and its algorithms are too long and complex to run a system. Therefore, a modified PID controller is formulate in order to predict duty cycle for DC-DC buck converter. It is able to regulate the voltage in the system with the case changing reference voltage, load and input voltage to produce better performance somehow like eliminate the steady-state error.

1.4 Objectives

The objectives of this project are:

i. To do system modeling on DC-DC buck converter

ii. To formulate a modified PID controller in order to predict a duty cycle for DC-DC buck converter.

iii. To analyse the performance of DC-DC buck converter.

1.5 Scope

i. Literature on DC-DC converter

ii. Literature on principle operation of DC-DC buck converter

iii. Obtain a mathematical model of DC-DC buck converter

iv. Design and simulate the PWM switching pattern of DC-DC buck converter

v. By using system modelling method and real plant method on DC-DC buck converter by using real plant

vi. Work on the system with and without controller and duty cycle prediction

vii. Analyse the performance of DC-DC buck converter

1.6 Limitation of the Project

The modified PID controller also has its own limitation. It just can response to smaller changes in reference voltage, load and input voltage. Since there is only a year to carry out this project, there is limited time to do research on Duty Cycle Prediction Control Technique too. The load change and input voltage by using this technique do not have enough time to discuss. Therefore, a further research on modified PID controller should be carried out so that the controller is able to respond in bigger change in reference voltage, load and input voltage while further research on Duty Cycle Prediction Control Technique need to be carried out to develop load change and input voltage.

CHAPTER 2

LITERATURE REVIEW

2.1 DC-DC Converter

DC-to-DC converter is an electronic circuit and it is able to convert direct current (DC) source from one voltage level to another. It is one of a type of electric power converter. DC-DC converter are divided into buck converter, boost converter and buck-boost converter. The function of the DC-DC converter is that it uses switch-mode configuration to control the input voltage and finally obtain a desired DC output voltage.

2.1.1 Uses of DC-DC Converter

DC to DC converters are normally applied in the portable electronic devices which uses batteries for example mobile phone or laptop computers. When the stored energy in the battery drained, the battery voltage declines. Therefore, switched DC to DC converters are used to increase voltage from a partially lowered battery voltage. Basically it prevents the use of multiple batteries and saves space. From the study, DC to DC converter circuits are able to regulate the output voltage for instance, high-efficiency LED power source it regulates the current through the LED, and it use as a simple charging pump which can increase the output voltage by double or triple it. In addition to this, photovoltaic systems also utilized this kind of converter to maximize the energy obtained.

2.1.2 PWM DC-DC Converters

Due to the research of Mor Mordechai Peretz, and Shmuel (Sam) Ben-Yaakov, they proposed on time-domain design of digital compensators for PWM DC-DC converters. This paper presented the development of digital controller of PWM DC–DC converters with a time-domain design method. The concept is applied to fit a digital PID model to the desired response. Furthermore, in the time domain and diversion errors from the continuous to discrete domain is accomplished by the method of proposed controller design. The study was to explore PID model controller to control the closed-loop performance that obtained from a system and the stability boundaries of the proposed time-domain controller design method[1].

2.2 Principle Operation of DC-DC Buck Converter

Mahesh Gowda N M, Yadu Kiran and Dr. S.S Parthasarthy proposed the principle of operation of a buck converter. When the MOSFET is ON, the input voltage is used in inversion through the diode. The diode should remain OFF if the MOSFET stays ON. The ON state of MOSFET means the diode is in OFF state. When the MOSFET turned ON, inductor current will build up. At the moment when MOSFET is OFF, inductor current has a finite value which is the peak value of the output current when it is in the primary chopper cycle. When the MOSFET OFF, this peak current occurs instantly. To prevent the unexpectedly drop of inductor current to zero, inductance will present. This voltage makes the diode turn into forward-biased and causes the current move along to continue and decay exponentially. Without the voltage source, the flow of current is called "Free-Wheeling", yet due to the energy stored in the inductor. The diode is to allow the free-wheeling path when MOSFET when it is OFF. The diode will thus turns ON when the MOSFET becomes off because of the presence of an energy stored inductor. The difference between successive cycles becomes negligibly small after few cycles. Thus he circuit conditions have reached steady state[2].

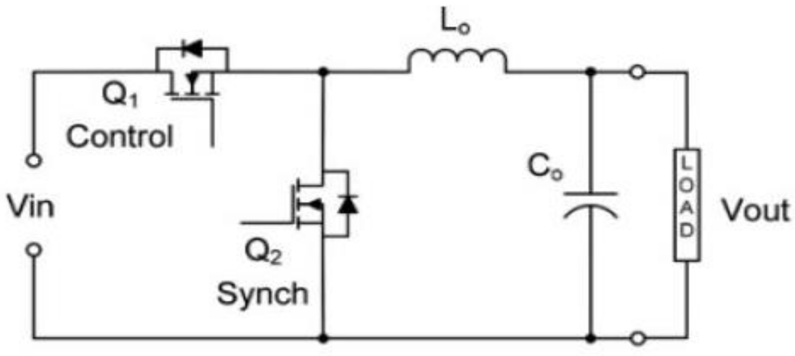


Figure 2.1: The Schematic Circuit Diagram of DC-DC Buck Converter

Figure above shows the schematic circuit diagram of a DC-DC buck converter. The diagram shows it is a simple circuit including two MOSFETs, an inductor, a capacitor, a resistor as load are used.

2.3 Modelling on DC-DC Buck Converter

Due to the research of Jose M. Sosa, P.R. Martinez-Rodriguez, G. Escobar, J.C. Nava-Cruz, and c.A. Limones-P Ozos proposed on the controller for a reduced output current ripple DC-DC buck converter. This paper presented without switching devices, the modelling of a DC-DC buck converter with lower output ripple can be successfully achieved. Sensitive loads for example the application in LED or high accuracy tools are needed for low output ripple. The function of buck converter is maintained and the output current and voltage ripples are extremely lower. In order to mitigate resonant behaviours, active damping must be provided. According to this, the regulation on output voltage and active damping can be achieved when the model-based controller proposed[3]. A fundamental component of this suggested controller has an estimation plan when changing of power under an intent output voltage[3]. Few simulations are developed to analyse the performance of closed-loop system[3].

Due to the research of Mahesh Gowda N M, Yadu Kiran and Dr. S.S Parthasarthy, they proposed on a mathematical model of a Buck Converter for simulation using Simulink. They explained the superior rise time, settling time and peak overshoot can be obtained by using MATLAB's tuning tools to obtain. In order to allow the application of the controller tuning tools gave by MATLAB, the system's transfer function is also discussed [2]. The paper mentioned that the default PID block is free to substitute with their own algorithms.

Due to the research of H. Abaali, he proposed on DC-DC buck converter with the design modelling control and simulation of. The buck converter is broadly used DC-DC converter topology[4]. This work proposes, using the current-mode control and method of state-space averaging to do the modelling of DC-DC buck converter. The operating point changes analysed the effectiveness of the suggested model and the control loop[4]. From this research, its effectiveness of the linear model of DC-DC buck converter was proved by using simulation results.

2.4 Proportional–Integral–Derivative Controller (PID Controller)

A proportional-integral-derivative controller (PID controller) is a generic feedback control mechanism that commonly used in industrial control systems. This is because it can mend the error between a measured process variable with a desired set point. After that a corrective action will be done to make the process become better. The PID controller calculation (algorithm) includes Proportional, the Integral and Derivative values. Proportional value will determine the reaction of current error, the integral value will determine the reaction of total errors while the derivative value will determine the reaction of rate at which the changing error occurred. The specific process requirements can be achieved by "tuning" the three values in the PID controller.

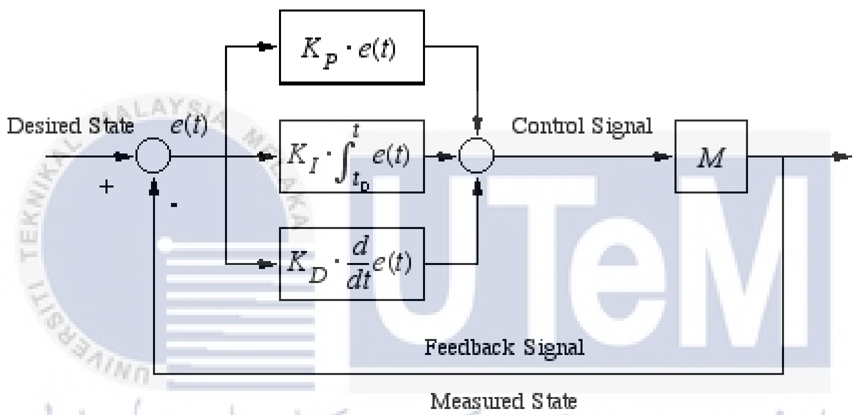


Figure 2.2: The PID Controller

Figure above shows the diagram of PID controller. The diagram shows the sum of proportional band or gain, integral gain or reset and derivative gain or rate.

2.4.1 Digital PID Controller

Due to the research of Chao-Ying Wang, Yang-Chieh Ou, Chih-Feng Wu and Muh-Tian Shiue, they proposed a PID controller design for voltage DC-DC buck converter[5]. DC-DC buck converter's phase margin is improved by the digital PID[5]. The behaviour model showed for the DC-DC buck converter of voltage-mode with ADC, digital PID controller and digital pulse width modulator (DPWM) based on the data of voltage error between input voltage and reference voltage is worked to analyse the responses by utilizing MATLAB Simulink[5].

2.4.2 Single-input fuzzy PID (SIF-PID) controller

Due to the research of Yubo Yuan, Changyuan Chang, Zhiqi Zhou, Xiaomin Huang and Yang Xu, they proposed designation of a single-input fuzzy PID controller for DC-DC buck converter based on the genetic optimization scheme. To enhance the performance of converter, a SIF-PID controller is designed. The three parameters of PID controller will alterate the fuzzy logic controller[6]. To decrease the computational burden, parallel diagonal lines in rule table can determine one-dimension rule vectors regarding the incline λ of the. To improve the coefficient λ, the genetic calculation is implied. This happen to make sure the simpler rule vectors and the first rule table are proportional regarding to control performance [6]. Simulation results presented the benefit of the controller mentioned.

Due to the research of Changyuan Chang, Yubo Yuan, Tianlin Jiang and Zhongjie Zhou, they proposed on the DC–DC buck converters used the field programmable gate array usage of a single-input fuzzy proportional–integral–derivative controller. This paper exhibited the outline and the DC–DC buck converters related with the field programmable gate array usage of a single-input fuzzy (SIF) proportional–integral–derivative (PID) control plot[7]. The amount of fuzzy rules being reduced. This minimizes SIF logic. Formation of The double-input rule table and TOEPLITZ structure formation is showed by analysing the system response curve[6]. The PID parameters regulated by the fuzzy logic controller based on the conditions of the power converters. Subsequently, the SIF-PID controller is like DIF-PID controller and it is better than the routine PID controller in terms of the control performance [7]. The simulation and experimental results has been validated with proposed controller.

2.4.3 PID Controller Tuning

Due to the research of Santanu Kapat, Member, and Philip T. Krein and Grainger, they proposed tuning on PID controller in a DC-DC converter. It is a method to reduce transient recovery time. This tuning concept will create high performance of PID controller. For large signal, minimum time transient recuperation can be performed by utilising a suitable auto-tuning principle. To deal with the ideal tuning principle, the geometric way is used[8]. The proposed principle is completed the estimation minimum time transient recuperation was shown in the large-signal transient. Meanwhile, a standard tuning rule can show the gains in small-signal transient[8]. Prototype of a buck converter is tested and the scheme mentioned is implemented.

Due to the research of Subhash Chander, Pramod Agarwal and Indra Gupta, they proposed on discrete and auto-tuned PID controller for DC-DC converter for rapid transient response. This paper enhanced discrete auto-tuning PID scheme for DC-DC converters where expected huge load changes or rapid response time. The calculation created at here is to tune discrete PID controller and get its parameters. To enhance its performance, it is connected to synchronous buck converter [9]. Based on the current process, the controller parameters are constantly modified to improve the transient response and rise time of the converter. Non-linear parameters is created when a synchronous buck converter is composed[9]. The effects of non-linear for example quantization, S/H, delay, and saturation are considered. Simulation results presented the effectiveness of the developed algorithms.

2.4.4 Sliding Mode PID Control

Due to the research of Khalifa Al-Hosani, Andrey Malinin and Vadim I. Utkin, they proposed on sliding mode PID control of buck converters. The objective of the controller designed is to control a DC-DC buck converter to track a desired set point voltage[10]. The intricacy of this controller emerges from the fact that the main information accessible to the controller is the deliberate error[10]. The buck converter inductance and capacitance are unknown.

Due to the research of Muhammad Attique Qamar, Jin Feng, Abbad Ur Rehman and Abid Raza, they proposed on discrete time sliding mode control of DC-DC buck converter. Two special systems are introduced by using the Discrete Time Sliding Mode Control[11]. To develop discrete time controller, emulation design approach and approximate discrete time equal system model is used. The comparison of the performance between emulation design and approximate equivalent system model for DC-DC buck converter is made[11]. The approximate equivalent model is a chattering-free control, indicates robustness to uncertainties and gives quick dynamic response.

2.4.5 Frequency Domain Based Controller

Due to the research of Husan Ali, Xiancheng Zheng, Xiaohua Wu, Shahbaz Khan and Dawar Awan, they proposed on frequency domain based controller design for DC-DC buck converter. With collection on a suitable control technique for stability improvement, extensively analysing on switched-mode DC-DC converters needed to be done for modelling and analysis[12]. Stability is very important in the design of all types of controllers, it can be achieved by correct value loop gain design for the closed loop system. From this research, frequency domain performance is able to measure the stability and behaviour of the converter. The gain margin and phase margin of the system is judged to analyse the stability of a system. The DC-DC converter has investigate three linear control[12]. Basically, poles and zeros should be placed at suitable locations and this is a basic technique utilizing in passive circuit components[12]. Measuring step response and the overshoot, rise time and settling time are evaluated by the time domain [12]. The simulation of the system is done by using MATLAB.

2.5 Modified PID Controller

The modified PID controllers used to stabilise the unstable plant. Basically, the P-parameters, I-parameters and D-parameters are independent with each other. Its function is to improve the characteristic and response of the system.

2.5.1 Modification and Application of Auto-tuning PID Controller

Due to the research of Nedjeljko Perić, Ivan Branica, Ivan Petrović, they presented a modified auto-tuning algorithm of the PID controller. The purpose of it is to apply in the larger class of the process. The description of the algorithms' functioning is to do modification. The suggested algorithm is applied in the programmable logic controller (PLC) Siemens SIMATIC S7-300. The suggested algorithms ensure good robustness properties and the results is shown in simulation[13].

2.5.2 A Modified Design of PID Controller of DC Motor Drives Using Particle Swarm Optimization PSO

Due to the research of Adel A. A. El-Gammal, Adel A. El-Samahy, they proposed a new particle swarm optimization technique to adjust the gain so that it can give the minimum integral error, settling time and overshoot. By using selected weighting factors, this new technique is able to change all objective functions to one objective function. Basically, the optimal PID controller parameters depends on the selected weighting factors and treated as dynamic optimizing parameters. Eventually the PSO acts as a dual optimization and best weighting factors. The results showed optimal PID controller is better than that of the traditional PID[14].

2.5.3 Determination of the PID Controller Parameters by Modified Genetic Algorithm for Improved Performance

Due to the research of Aytekin Bagis, this paper presented an efficient and rapid tuning method based on a modified genetic algorithm (MGA) structure to approach the optimal parameter of the proportional-integral-derivative (PID) controller. This tuning method is to ensure the specifications of the desired system will reach satisfaction[4]. To obtain high efficiency search, the optimized algorithm regarding on the integration of conventional genetic algorithm has been developed. Eventually the PID control system can be improved by this method.

CHAPTER 3

METHODOLOGY

3.1 Method

MATLAB Simulink Software has been chosen as the method used. MATLAB Simulink Software is a software programming. It can do modelling, simulating and analysing different types of systems. Its library consists of graphical block and can arrange regarding on different system that want to develop.

MATLAB (matrix laboratory) is a multi-worldview numerical computing environment and it is also a fourth-era programming language. Basically, MATHWORKS created the exclusive programming language and to be used in different types of systems. Eventually, it can used for matrix controls, plotting of data and functions, calculations, production of UIs and interfacing with projects written in different language, including C, C++, C#, Java, Fortran and Python.

Besides, the process to carry out this project has been described in the flowchart. Initially, start the project and identify the parameters such as input voltage, output voltage, ripple current, switching frequency, changes on voltage, inductor resistance, values of duty cycle, inductance and capacitance. Next, work on system without and with controller and duty cycle prediction by using system modeling method and real plant method. After each of the system, run the testing and analyse its result. If the testing is yes, proceed to the next, if the testing is no, go back to the system and analyse the problem. Proceeding until the duty cycle prediction, if the answer is yes, means successfully develop new feedback controller. If no, analyse the problem. The below shows the flowchart of this project.

3.2 Flowchart

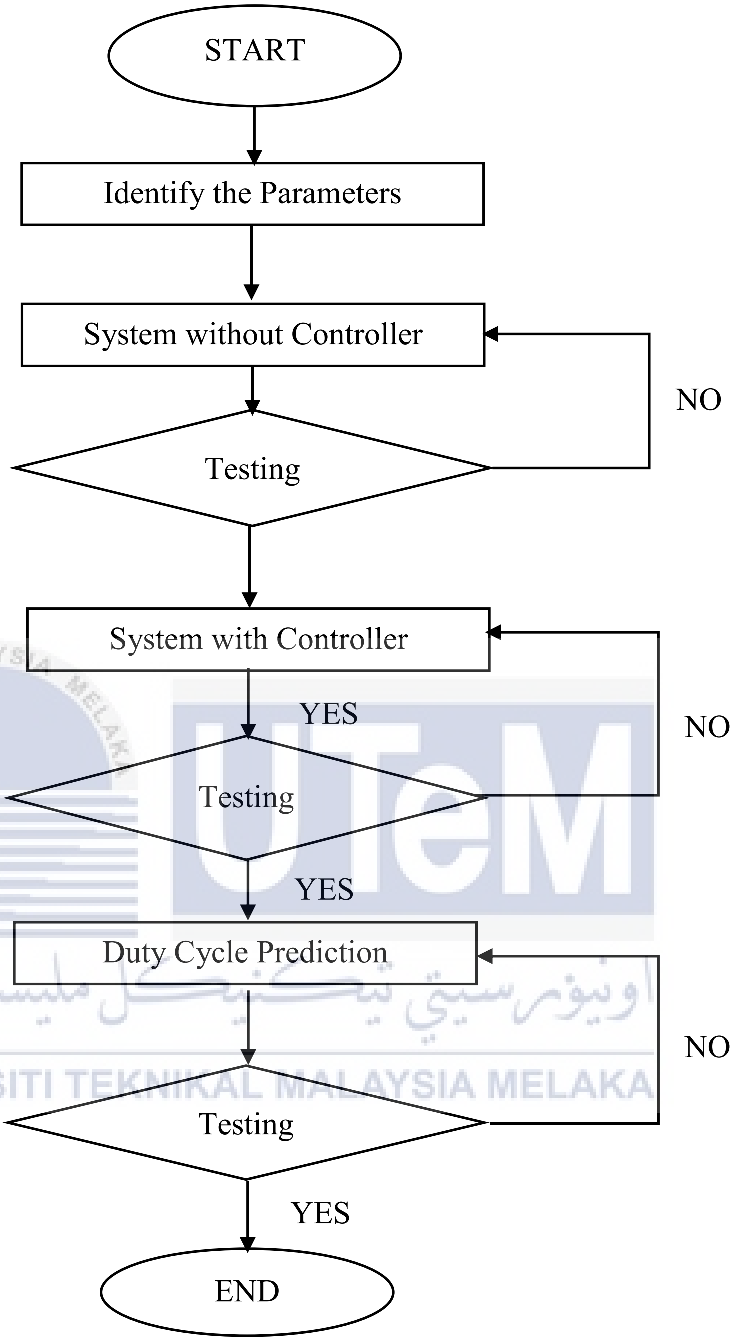


Figure 3.1: Flow Chart

Figure 3.1 shows the flowchart of the project. It shows the steps to do throughout this project.

3.3 Identify the Parameters

There were five basic components that normally utilise in DC-DC Buck Converter to run this simulation. There were power supply, switch, diode, inductor, capacitor and resistor (load).

Changes on voltage, ΔV is always 1% of output voltage.

Formula:

$$V_{out} = V_{in}\ x\ D \tag{3. 1}$$

$$D = \frac{T_{on}}{T_{on}+T_{off}} \tag{3. 2}$$

$$L = \frac{D(V_{in}-V_{out})}{I_{ripple}\ x\ F_s} \tag{3. 3}$$

$$C = \frac{I_{ripple}}{8\ x\ F_s\ x\ \Delta V} \tag{3. 4}$$

Table 3.1: The Set Parameters and Values of DC-DC Buck Converter

Parameters	**Values**
Input Voltage, V_{in}	12 V
Output Voltage, V_{out}	5 V
Ripple Current, I_{ripple}	20%
Switching Frequency, F_s	20k Hz
Changes on voltage, ΔV	0.05V
Inductor resistance, R_1	0.001Ω
Load resistance, R_L	10Ω

Table 3.1 shows the set parameters and values of DC-DC Buck converter.

Calculation:

By using the formula (3.1), (3.2), (3.3) and (3.4), the parameters and values of duty cycle, inductance and capacitor were calculated as shown in the Table 3.2.

Table 3.2: The Values of Duty Cycle, Inductor and Capacitor

Parameters	**Values**
Duty Cycle	0.417
L	750µH
C	25µF

Table 3.2 shows the parameters and values of Duty Cycle, Inductance and Capacitance.

3.4 Modeling Method

The modeling method used to represent the behaviour of actual circuit or electronic device. This method is related to obtain the mathematical model of a system

3.4.1 System Modeling

Electronic circuit simulation uses mathematical model to replicate the behaviour of actual circuit of DC-DC Buck Converter circuit. Figure 3.2 shows that the DC-DC buck converter circuit has been transformed into the Laplace form.

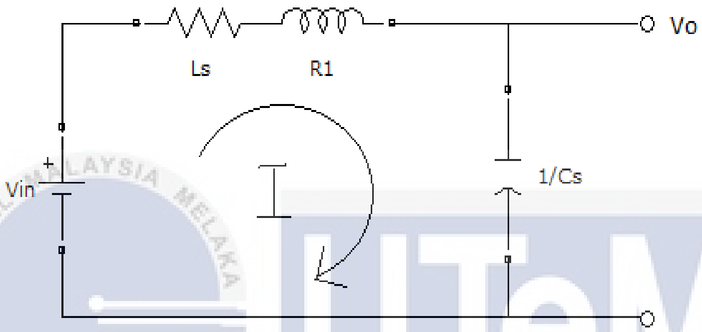


Figure 3.2: DC-DC Buck Converter Circuit

The steps below shows the method to obtain the plant, $\frac{Vo}{V_{in}}$ of the system,

$$V_{in} = I(Ls + R_1 + \frac{1}{Cs}) \tag{3.5}$$

$$V_o = I\left(\frac{1}{Cs}\right) \tag{3.6}$$

$$I = V_o Cs \tag{3.7}$$

Substitute Equation (3.7) in Equation (3.5),

$$V_{in} = V_o Cs(Ls + R_1 + \frac{1}{Cs}) \quad (3.\ 8)$$

$$V_{in} = (LCs^2 + R_1 Cs + 1)V_o \quad (3.\ 9)$$

$$\frac{Vo}{V_{in}} = \frac{1}{LCs^2 + R_1 Cs + 1} \quad (3.\ 10)$$

3.4.2 System without Controller

The plant system without controller by using coding as below Figure 3.3 and Figure 3.4 respectively in MATLAB to plot the step response and its root locus,

```
Command Window
>> R1= 0.001;
L=750e-6;
C=25e-6;
num=[1];
den= [L*C R1*C 1];
G=tf(num,den); %Plant
figure; plot (step(num,den))
```

Figure 3.3: Plot Step Response of System without Controller

Figure 3.3 shows plotting step response of system without controller in the MATLAB coding.

```
Command Window
>> clear all
R1=0.001;
L=750e-6;
C=25e-6;
num=[1];
den= [L*C R1*C 1];
G=tf(num,den); %Plant
%figure; plot (step(num,den))
rlocus(G)
>>
```


Figure 3.4: Plot Root Locus of System without Controller

Figure 3.4 shows plotting root locus of system without controller in the MATLAB coding.

3.4.3 System with Controller

The plant system with controller by using coding as below Figure 3.5 and Figure 3.6 respectively in MATLAB to plot the step response and its root locus,

```
Command Window
>> R1=0.001;
L=750e-6;
C=25e-6;
num=[1];
den= [L*C R1*C 1];
G=tf(num,den); %Plant
%figure; plot (step(num,den))
%rlocus(G)

%Controller  Modified parameter
Kd=0.002;
Td=0.0003;
K=100;
num1=[Kd 0]; %H
den1=[Td 1]; %H
num2=[K]; %A
den2=[1 0];%A
H=tf(num1,den1);%H
A=tf(num2,den2);%A
B=feedback(G,H);
C=series(A,B);
%closed loop TF
T=feedback(C,1);
%F=tf(T)
figure; step(T)   % Result with controller
>>
```

Figure 3.5: Plot Step Response of System with Feedback Controller

Figure 3.5 shows plotting step response of system with modified PID controller in the MATLAB coding.

```
Command Window
>> R1=0.001;
L=750e-6;
C=25e-6;
num=[1];
den= [L*C R1*C 1];
G=tf(num,den); %Plant
%figure; plot (step(num,den))
%rlocus(G)

%Controller  Modified parameter
Kd=0.002;
Td=0.0003;
K=100;
num1=[Kd 0]; %H
den1=[Td 1]; %H
num2=[K]; %A
den2=[1 0];%A
H=tf(num1,den1);%H
A=tf(num2,den2);%A
B=feedback(G,H);
C=series(A,B);
%closed loop TF
T=feedback(C,1);
%F=tf(T)
%figure; step(T)    % Result with controller
rlocus(T)
fx >>
```

Figure 3.6: Plot Root Locus of System with Feedback Controller

Figure 3.6 shows plotting root locus of system with modified PID controller in the MATLAB coding.

3.4.4 Duty Cycle Prediction

3.4.4.1 Predicting the Duty Cycle Curve through Placement of the Dominant Closed-Loop Poles

The linear relationship between the bridge voltage (V_B) and the Duty Cycle (D),

$$V_B = DV_{in} \tag{3. 11}$$

The bridge voltage V_B is considered an output voltage to the plant, allowing (3.11) to be written as:

$$V_o = DV_{in} \tag{3. 12}$$

From Equation (3.12), the continuous domain duty cycle can be computed as:

$$\mathrm{D}(k) = \frac{c(\mathrm{k})}{1.5 \text{ x } \mathrm{V_m}} \tag{3. 13}$$

Where $c\,(\mathrm{k})$ is the output response, respectively subjected to the reference input, in continuous domain. Equation (3.13) expresses $D_{(k)}$ as being linear to the total of output response $c_{(k)}$ of the closed-loop system. The control action of the duty cycle curve $D_{(k)}$ can therefore be predicted and simplified through an investigation of the closed-loop output response, $c_{(k)}$.

The basic characteristic of the output response of a closed-loop system usually relates closely to the location of the dominant closed-loop poles. The dominant poles dominate the output response since their contribution takes a longer time/locus path than those of the other poles. Predicting the duty cycle curve of the modified PID controller using placement of the dominant closed-loop poles can be a new control technique approach (namely as Duty Cycle Prediction Control Technique), used as the control action of D. The process of determining this prediction D curve is easier by analysing the system separately (i.e. system subjected to the reference input.

3.4.4.2 Predicting the Curve of a System Subjected to a Reference Input

The closed loop of the transfer function (feedback controller) is determined by MATLAB, typed values of L=750mH, $R_1 = 0.001\Omega$, C=25µF, $K_p = 100$, $T_D = 0.0003$, and $K_D = 0.002$ into the system, the closed-loop transfer function of the proposed system, subjected to the reference input, is,

$$T_r(s) = \frac{0.03_s+100}{5.625e^{-12}s^4+1.876e^{-8}s^3+0.0023s^2+1.03s+100} \tag{3. 14}$$

Zero: z1= -3.3333 x 10^3

p1= -0.0307 x 10^{-4}, p2= -0.0142 x 10^{-4} and p3, p4= (-0.1443$\pm$j2.0136) x 10^{-4}

p1 and p2 are the dominant poles because of their location (the closest to the imaginary axis). Figure 3.7 shows the system output response $T_r(s)$. The curve of the response similar to that of the overdamped system, which has a pole at the origin (from the unit step input) and two real poles (known also as dominant poles, from the system). The input pole at the origin generates the constant forced response and each of the dominant poles on the real axis generates an exponential natural response whose exponential frequency equals the location of the poles.

The general output response $c(t)$ of the overdamped system can be written as

$$c(t) = K_1 + K_2e^{-\sigma 1t} + K_3e^{-\sigma 2t} \tag{3. 15}$$

Where, K_1, K_2, and K_3 are the coefficient values, and σ1, σ2 are the locations of the dominant poles.

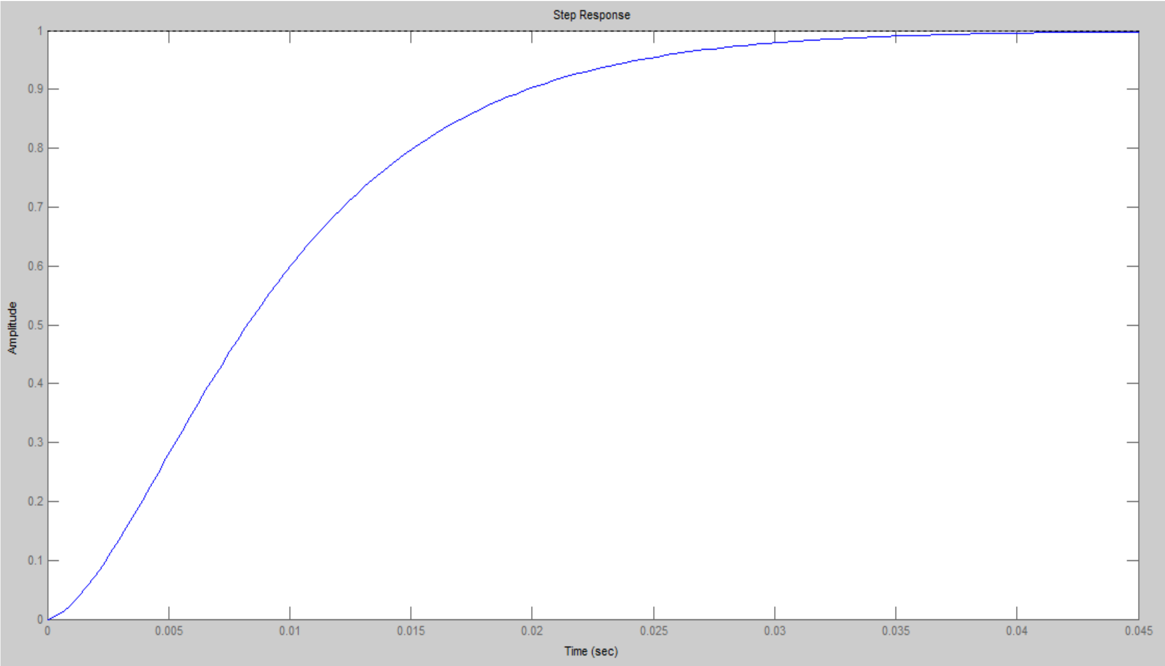


Figure 3.7: The Step-reference Output Response T_r

The values of K_1, K_2, and K_3 of Equation (3.15) can be solved if the locations of the dominant poles (σ_1, σ_2) are known (through Laplace partial method, refer to Appendix C). Substituting the dominant poles p2 and p3 into Equation (3.15) gives:

$$c(t) = 1 + 0.8607e^{-3.07e-6t} - 1.8609e^{-1.42e-6t} \quad (3.\ 16)$$

Figure 3.8 below shows the output response of $c(t)$. Both the responses (refer to Figure 3.7 and 3.8) show that Equation (3.16) can be used as the prediction curve of the duty cycle (D) for systems subjected to the reference input.

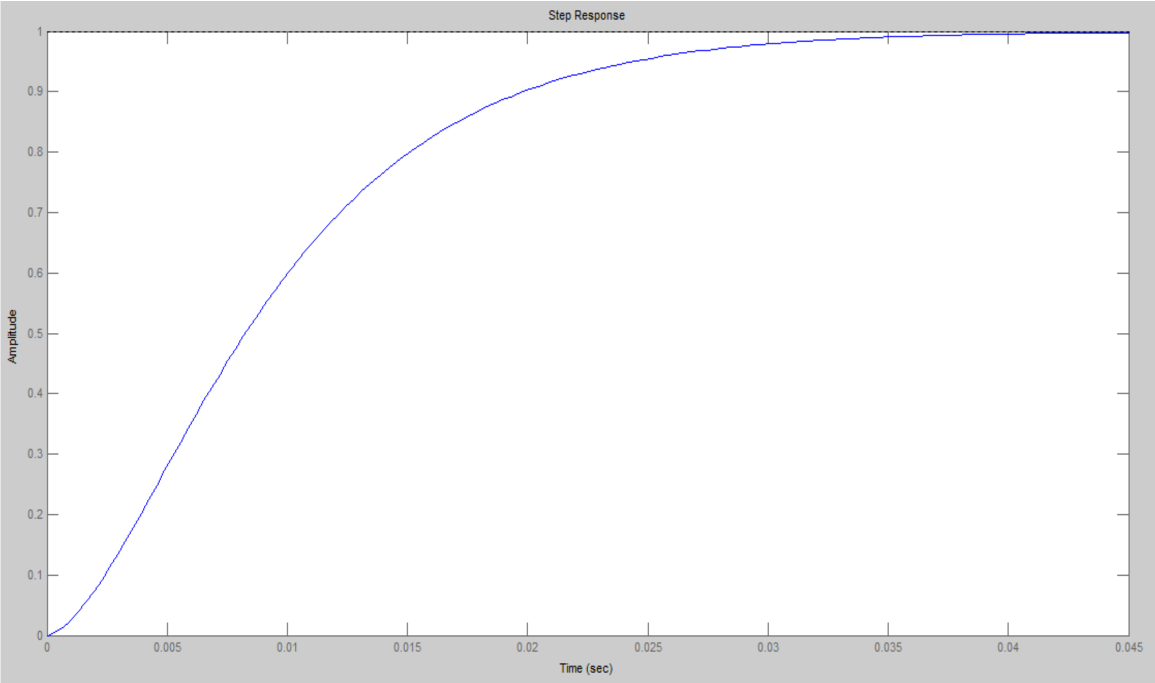


Figure 3.8: The Output Response of $c(t)$

Figure 3.8 shows the output response of $c(t)$.

3.4.4.3 Implementing the Proposed Duty Cycle Prediction Control Technique

The algorithms of Duty Cycle Prediction Control Technique is determined by equation (3.16), yields,

$$c(t) = 1 + 0.8607e^{-3.07e-6t} - 1.8609e^{-1.42e-6t}$$

Figure 3.9 below is a block diagram showing implementation of the modified PID controller technique and the proposed D-prediction curve system in MATLAB/Simulink.

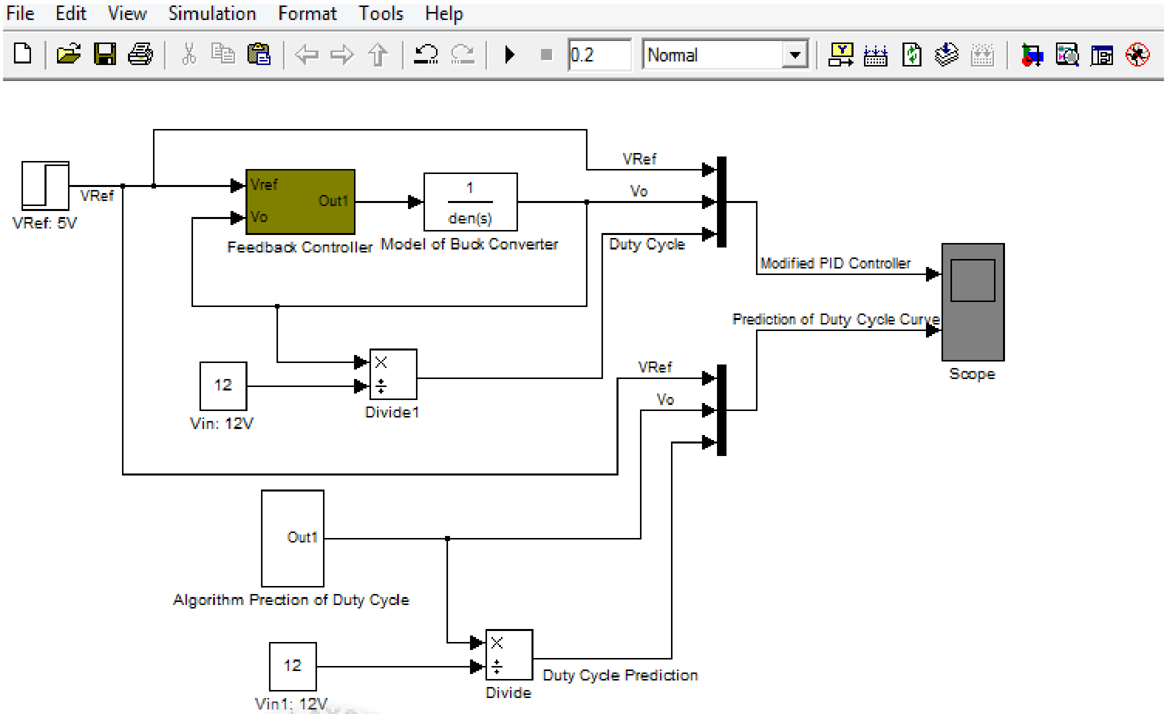


Figure 3.9: The Model System by Using Transfer Function with Modified PID Controller and The Proposed D Prediction Curve Technique, Drawn On MATLAB/Simulink

3.5 Real Plant Method

Real Plant method is the method that uses the construction on DC-DC Buck Converter and inserts it into the system.

3.5.1 System without Controller

The manually construction on PWM as shown in figure 3.10 below used the operator greater or equal to than to ensure the output voltage obtain is 5V. The repeating sequence is used to ensure that the signal produce is in repeating from. While these two components are connected to input which will be connected to duty cycle and output which will be connected to ideal switch.

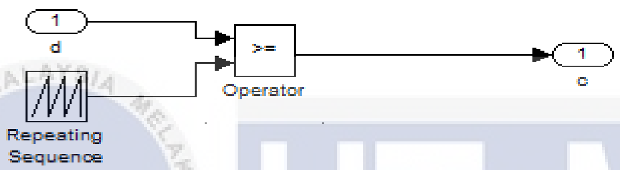


Figure 3.10: Manually Construction on PWM

There are three types of cases to be tested and shown in the below, which are change the reference voltage, change the load and change the input voltage.

Case 1: Change the reference voltage, $Vref$

Figure 3.11 as below shows that the change in reference voltage from 5V to 7V. The initial value of step input is set as 5V while the final value is set as 7V. The scope has 2 inputs, reference output voltage and output voltage.

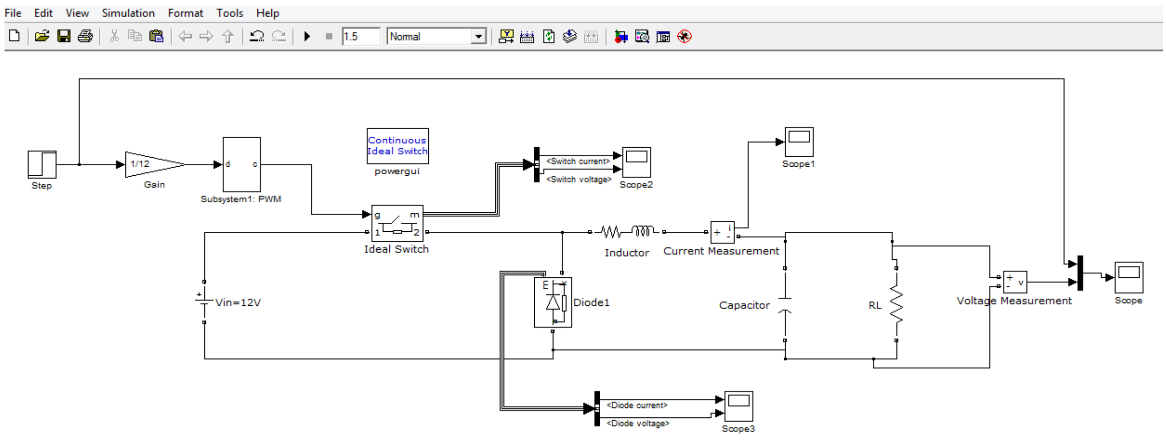


Figure 3.11: Reference Voltage Changed

Case 2: Change the load, R_L

Figure 3.12 shows that the load changed from originally 10Ω to 6.25Ω. Three resistors are installed in parallel to obtain 6.25Ω, the three resistors used were 100Ω, 20Ω and 10Ω. The scope has 2 inputs, reference output voltage and output voltage.

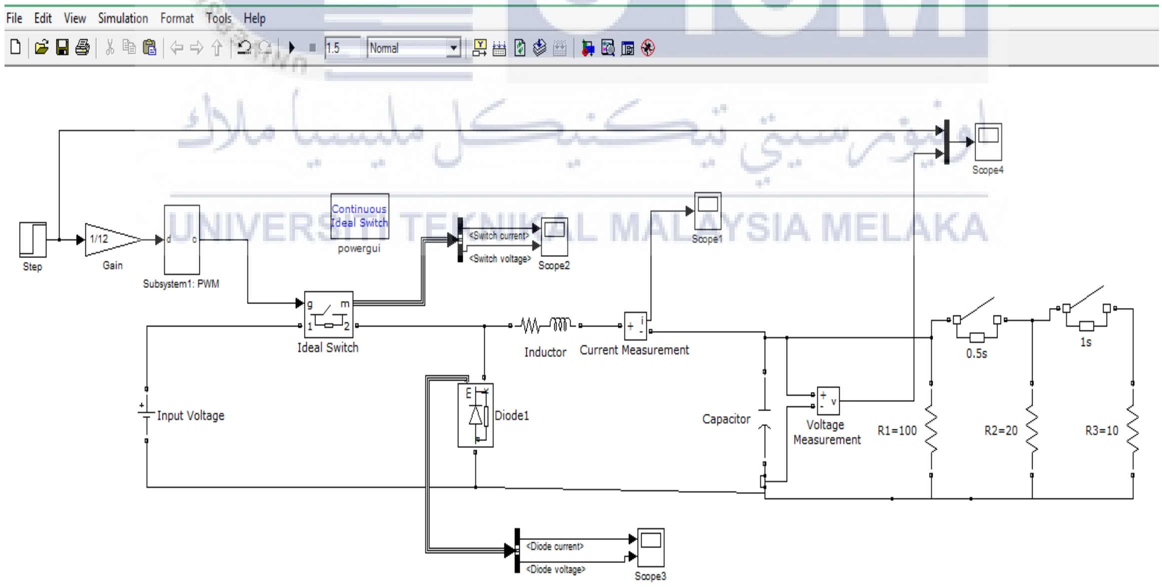


Figure 3.12: Load Changed

Formula to calculate resistor in parallel:

$$R = \frac{1}{\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}} \tag{3.18}$$

By using the equation (3.18),

Where $R_1 = 100\Omega;\ R_2 = 20\Omega;\ R_3 = 10\Omega$

$$R = \frac{1}{\frac{1}{100\Omega}+\frac{1}{20\Omega}+\frac{1}{10\Omega}} = 6.25\Omega$$

Case 3: Change the input voltage, Vin

Figure 3.13 shows that the input voltage change from 12V to 10V, while the input voltage is set as 10V. The scope has 2 inputs, reference output voltage and output voltage.

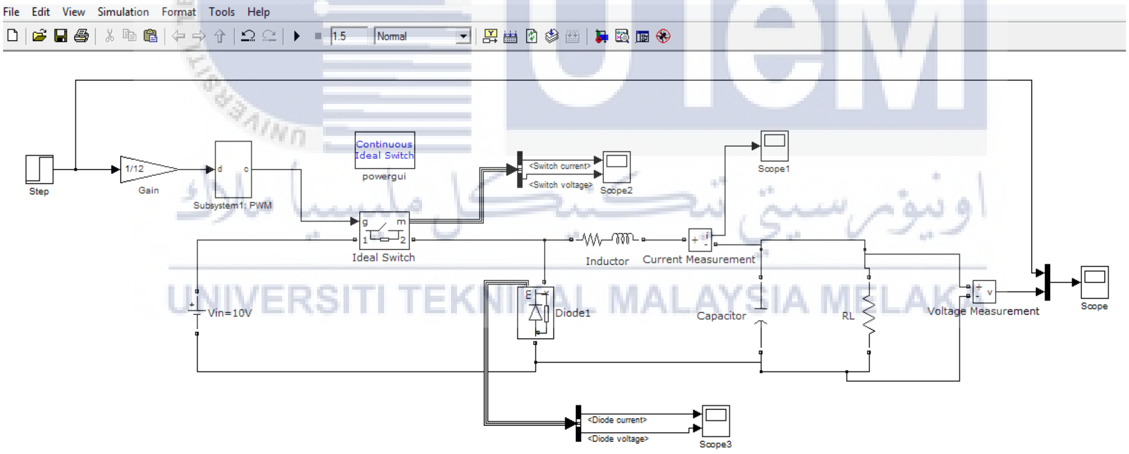


Figure 3.13: Input Voltage Changed

3.5.2 System with Controller

System with controller means insert the modified PID controller inside the system.

3.5.2.1 Modified PID Controller

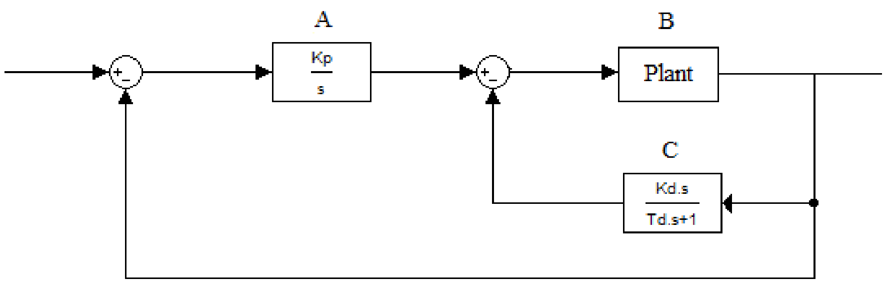


Figure 3.14: A Minor Loop Feedback Controller

Figure 3.14 shows that the proposed SISO approach with minor-loop voltage control. The controller has a derivative compensator (C) in a minor loop around the plant and a proportional integral compensator (A) in the forward path. This controller is useful than in step changes in reference voltage by particularly. A cascade derivative action in forward path will saturate plant input. The advantage of using this controller because it can control the transient response to desired response and reach zero steady-state error.

However, the root locus technique was used in designing the three values here which were K_p, K_d and T_d. This technique forces the root locus to pass through the desired closed-loop poles and meets system performance specifications on s-plane. As the loop gains vary, the closed-loop poles should be clearly known. The desired response specification can be met through a suitable gain value. The procedures of tuning the gain as below:

a) Find an equivalent closed-loop transfer function,

$$\frac{e(Tds+1)}{as^4+bs^3+cs^2+Ds+E} \tag{3. 19}$$

wheres,

$a = T_d LC$

$b = T_d RC + LC$

$c = T_d + RC + K_d$

$d = 1 + K_p T_d$

$e = K_p$

b) Choose value of T_d where -1/T_d is a location of zero and must be far away to the left of the s-plane so that it can be ignored. Therefore, Td is chosen as 0.0003.

c) For K_d, it was selected as 0.002 because Kd need to be about 10 times Td to avoid the manipulated variable, $u(t)$, as an impulse function when a step-change applied to the plant. $u(t)$ will become sharp pulse function.

d) K_p, is the system loop gain. It is a variable and it does not change the root locus shape. Therefore, K_p is assumed as 100.

By using the equation(3.19), the parameters and values of modified PID controller is calculated as Table 3.3 belows,

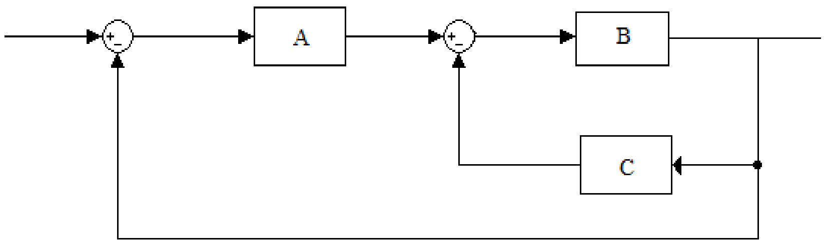
Table 3.3: The Parameters and Values of Modified PID Controller

Parameters	**Values**
Derivative time, T_d	0.0003s
Derivative gain, K_d	0.002
Proportional gain, K_p	100

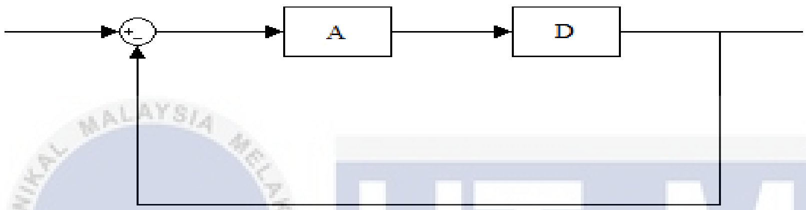
Table 3.3 shows the parameter and values used in the Modified PID Controller.

3.5.2.2 Simplifying process

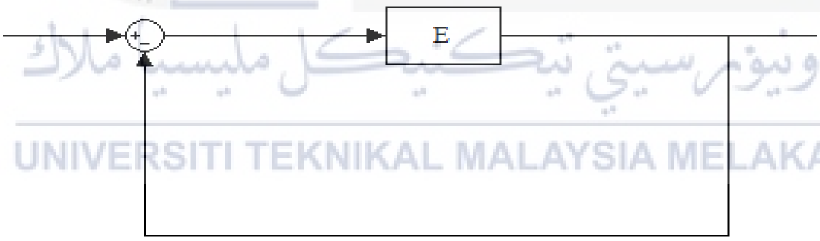
Simplifying process is a process that make the circuit become simpler after added the modified PID controller as shown in the Figure 3.15 (a), (b), (c) and (d) below. The following shows step-by-step to simplify the circuit become the simplest system.



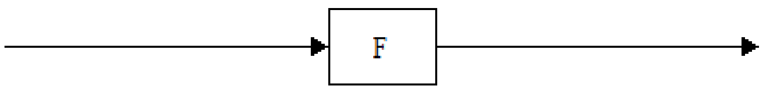
(a): General system



(b): D obtained due to C is the negative feedback of C



(c): E obtained due to A series with D



(d): F obtained due to summation of E

Figure 3.15: (a), (b), (c) and (d)

Figure 3.13 (a), (b), (c) and (d) shows the simplifying process of general system to the simplest system. This simplifying process is to make easier on construction system and making analysis.

3.5.2.3 Construction on Feedback Controller in MATLAB/Simulink

The Figure 3.16 as below shows the feedback controller which is constructed in MATLAB/Simulink.

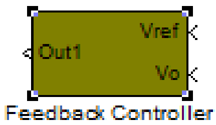


Figure 3.16: Manually Construction on Modified PID Controller in Simulink

Figure 3.16 shows manually construction on modified PID controller in Simulink. It consists of 2 inputs, $Vref\ and\ Vo$ and also an output.

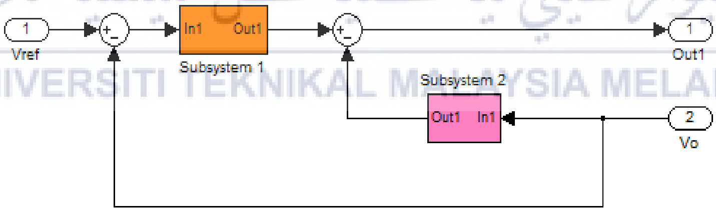


Figure 3.17: Inner Part of Modified PID Controller

Figure 3.17 shows inner part of modified PID controller. It consists of 2 subsystems which are subsystem 1 and subsystem 2. The input of subsystem 1 connects to $Vref$ while its output connects to summation of output of subsystem 2. The input of subsystem 2 connects to Vo.

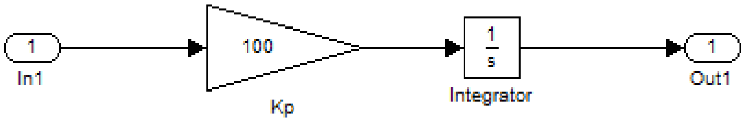


Figure 3.18: Subsystem 1 of Modified PID Controller

Figure 3.18 shows subsystem 1 of modified PID controller. It consists of K_p and integrator.

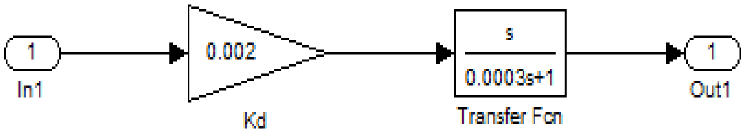


Figure 3.19: Subsystem 2 of Modified PID Controller

Figure 3.19 shows subsystem 1 of modified PID controller. It consists of K_d and the transfer function that consists of T_d.

There are three types of cases to be tested and shown in the below, which are change the reference voltage, change the load and change the input voltage.

Case 1: Change the reference voltage, *Vref*

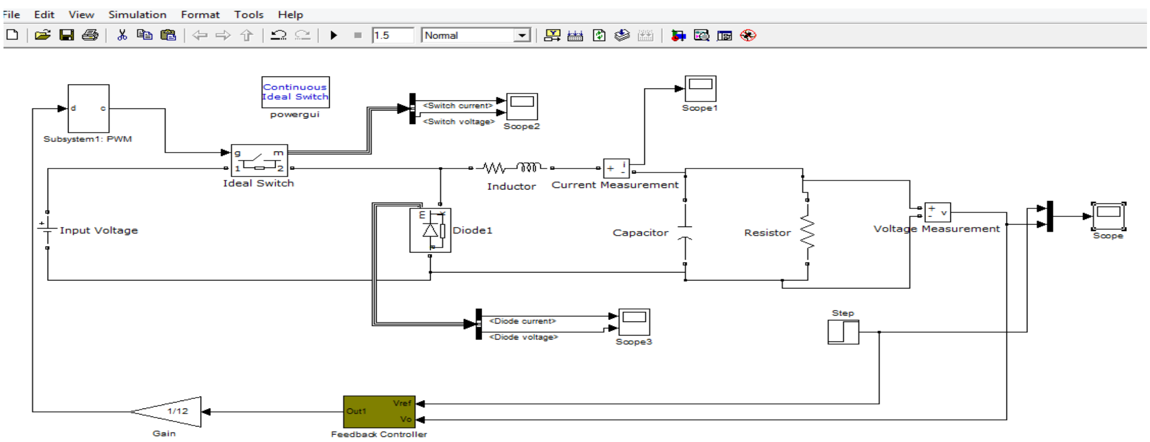


Figure 3.20: Reference Voltage Changed

Figure 3.20 shows that the system is connected to a feedback controller, modified PID controller. It also shows the change in reference voltage from 5V to 7V. The initial value of step input is set as 5V while the final value is set as 7V. The scope has 2 inputs, reference output voltage and output voltage.

Case 2: Change the load, R_L

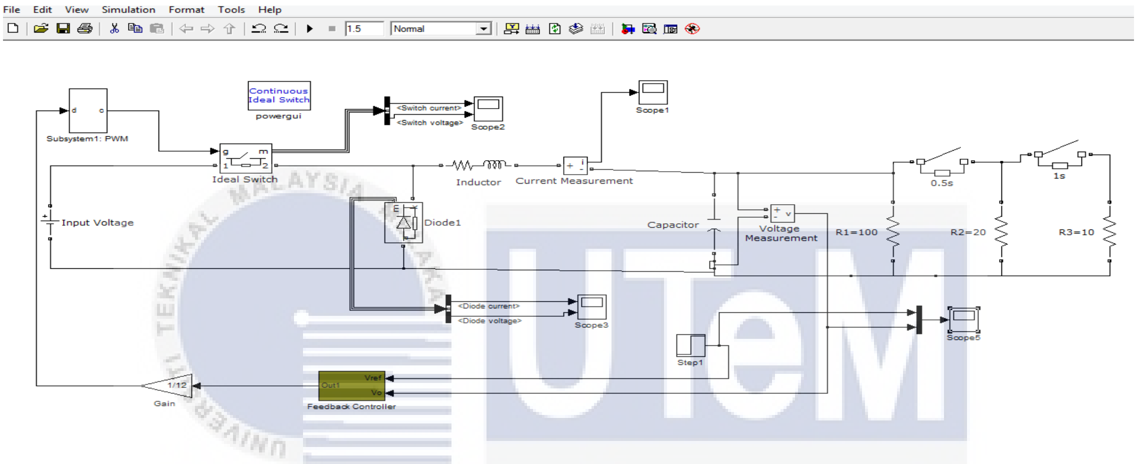


Figure 3.21: Load Changed

Figure 3.21 shows that the system is connected to a feedback controller, modified PID controller. It also shows the load changed from originally 10Ω to 6.25Ω. Three resistors are installed in parallel to obtain 6.25Ω, the three resistors used were 100Ω, 20Ω and 10Ω. The scope has 2 inputs, reference output voltage and output voltage.

By using the equation (3.18),

Since $R_1 = 100\Omega;\ R_2 = 20\Omega;\ R_3 = 10\Omega$

$$R = \frac{1}{\frac{1}{100\Omega} + \frac{1}{20\Omega} + \frac{1}{10\Omega}} = 6.25\Omega$$

Case 3: Change the input voltage, Vin

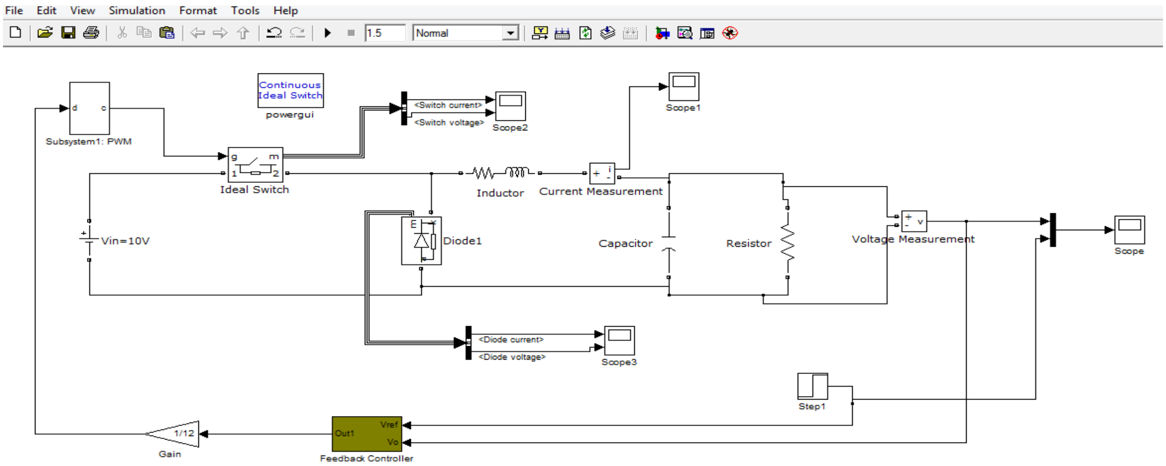


Figure 3.22: Input Voltage Changed

Figure 3.22 shows that the system is connected to a feedback controller, modified PID controller. It also shows the input voltage change from 12V to 10V, while the input voltage is set as 10V. The scope has 2 inputs, reference output voltage and output voltage.

3.5.3 Duty Cycle Prediction

The algorithms of Duty Cycle Prediction Control Technique is determined by Equation (3.16), yields,

$$c(t) = 1 + 0.8607e^{-3.07e-6t} - 1.8609e^{-1.42e-6t}$$

Figure 3.23 below is a block diagram showing implementation of the modified PID controller technique and the proposed D-prediction curve system in MATLAB/Simulink.

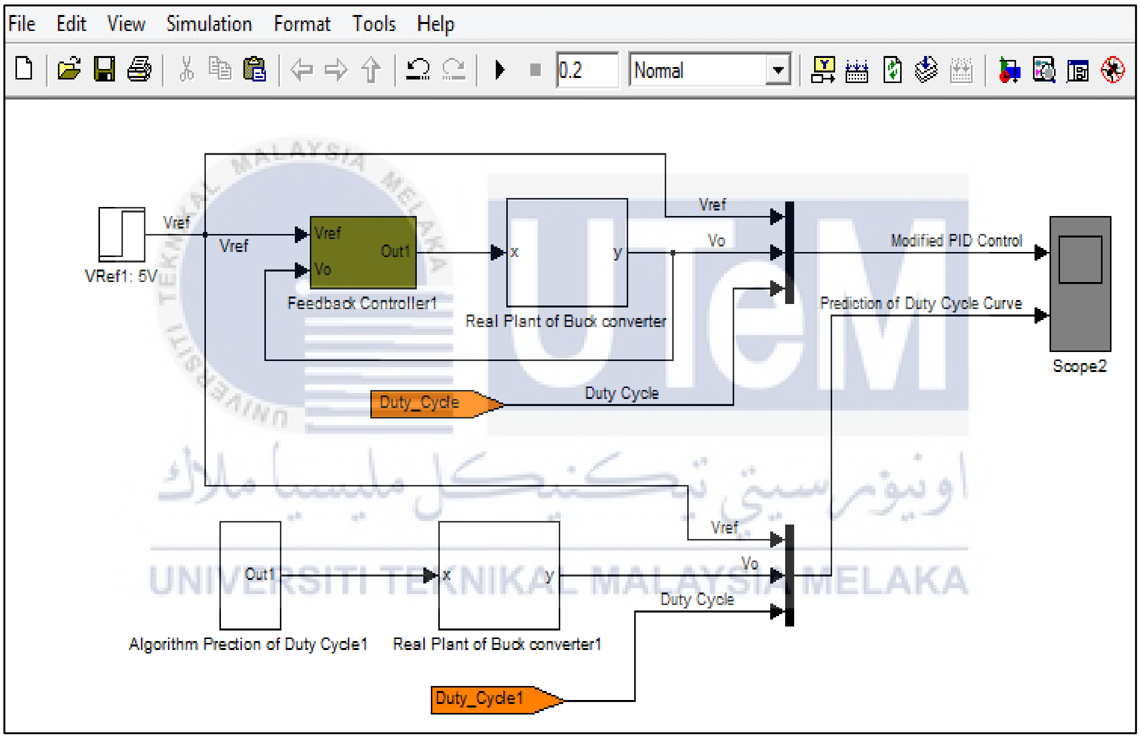


Figure 3.23: The System by Using Real Plant with Modified PID Controller and The Proposed D Prediction Curve Technique, Drawn on MATLAB/Simulink.

CHAPTER 4

RESULT AND ANAYLSIS

4.1 Modeling Method

The modeling method used to represent the behaviour of actual circuit or electronic device. The result by using this method are shown in the below.

4.1.1 System without Controller

Modeling method work on system without controller of DC-DC Buck Converter has been carried out. Figure 4.1 and Figure 4.2 below show the step response and root locus of the system. It was constructed in MATLAB/Simulink.

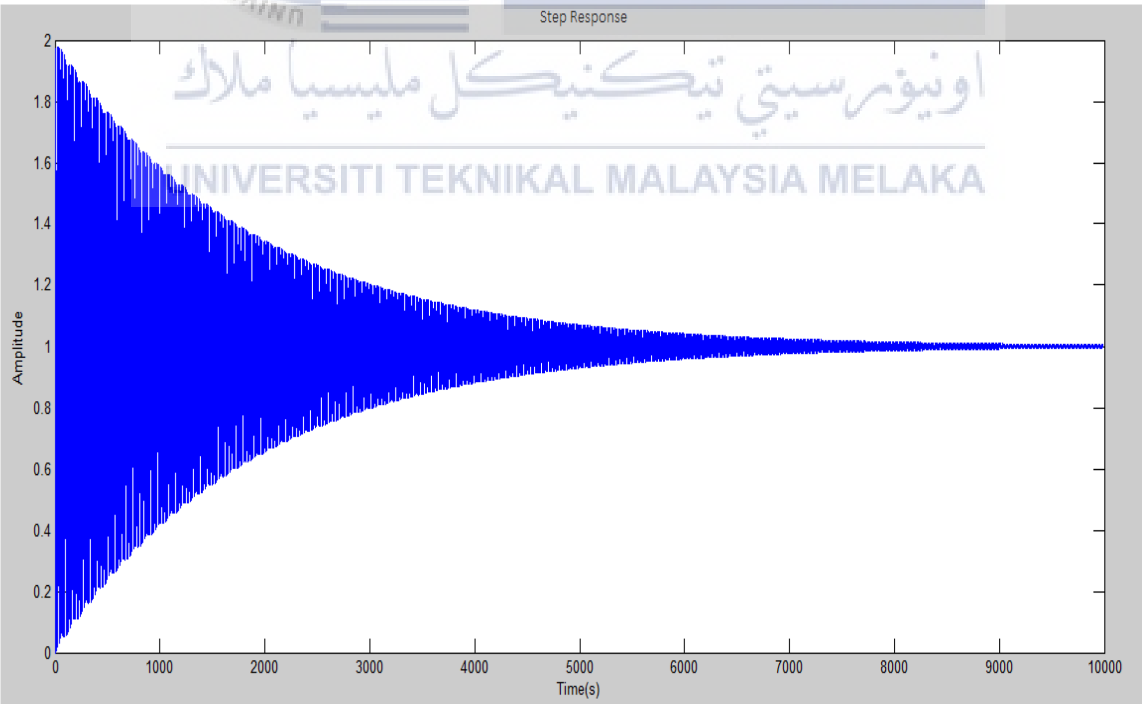


Figure 4.1: Step Response of System without Controller

Figure 4.1 shows the step response of the system and this is the result of system without controller. The oscillation occurred and the settling time was around 9000s. Therefore, the transient response was not good. In conclusion, a controller needed to produce good transient response.

The following Figure 4.2 shows the root locus of the system without controller.

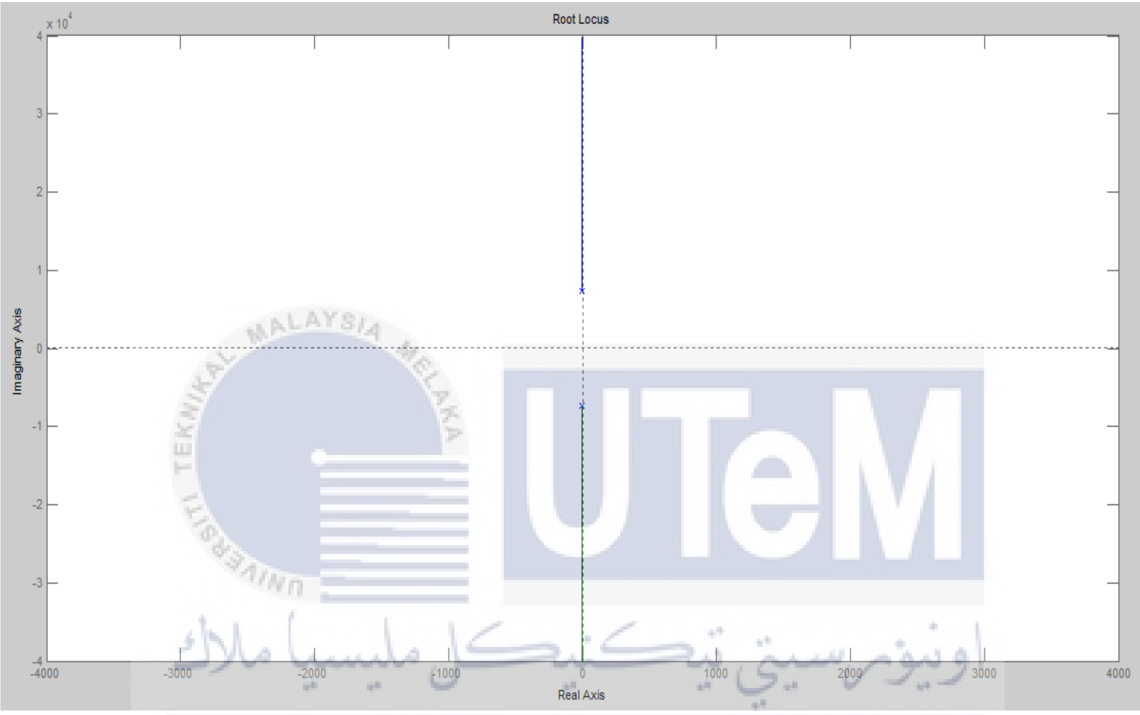


Figure 4.2: Location of Dominant Poles in System without Controller

Poles= (-0.0007$\pm$7.3030i) $x\ 10^{-3}$

Zeta= 0.9129$x\ 10^{-4}$

4.1.2 System with Controller

Modeling method work on system with controller of DC-DC Buck Converter has been carried out. Figure 4.3 and Figure 4.4 below show the step response of the system and root locus of the system. It was constructed in Matlab/Simulink.

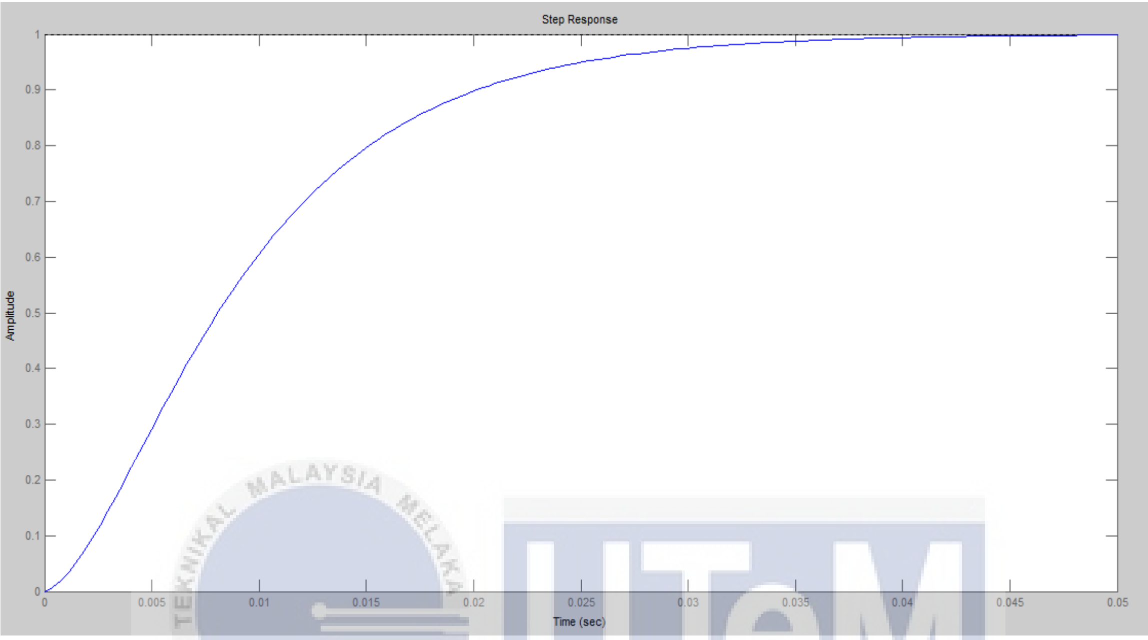


Figure 4.3: Step Response of System with Modified PID Controller

Figure 4.3 shows the step response of the system and this is the result of system with controller. No more oscillation occurred and the settling time was around 0.04s. Therefore, the transient response was good. In conclusion, a controller needed to produce good transient response.

The following Figure 4.4 shows the zeros and dominant poles of the system with controller.

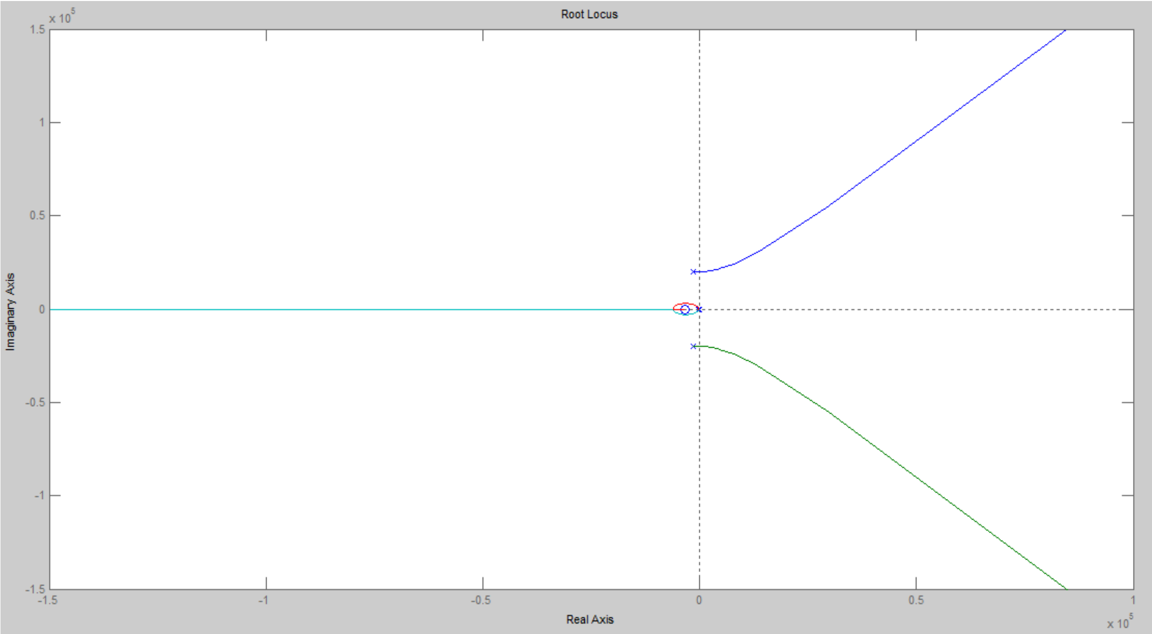


Figure 4.4: Location of Zeros and Dominant Poles in System with Modified PID Controller

Zero: z1= -3.3333 x 10^3

Poles:p1= -0.0307 x 10^{-4}, p2= -0.0142 x 10^{-4} and p3, p4= (-0.1443±j2.0136) x 10^{-4}

Zeta= 0.9129x 10^{-4}

4.1.3 Duty Cycle Prediction

The reference, output responses and the duty cycle prediction curve for both control systems are shown in Figure 4.5, for tests on step-up reference input, 0-5V at 0.05s.

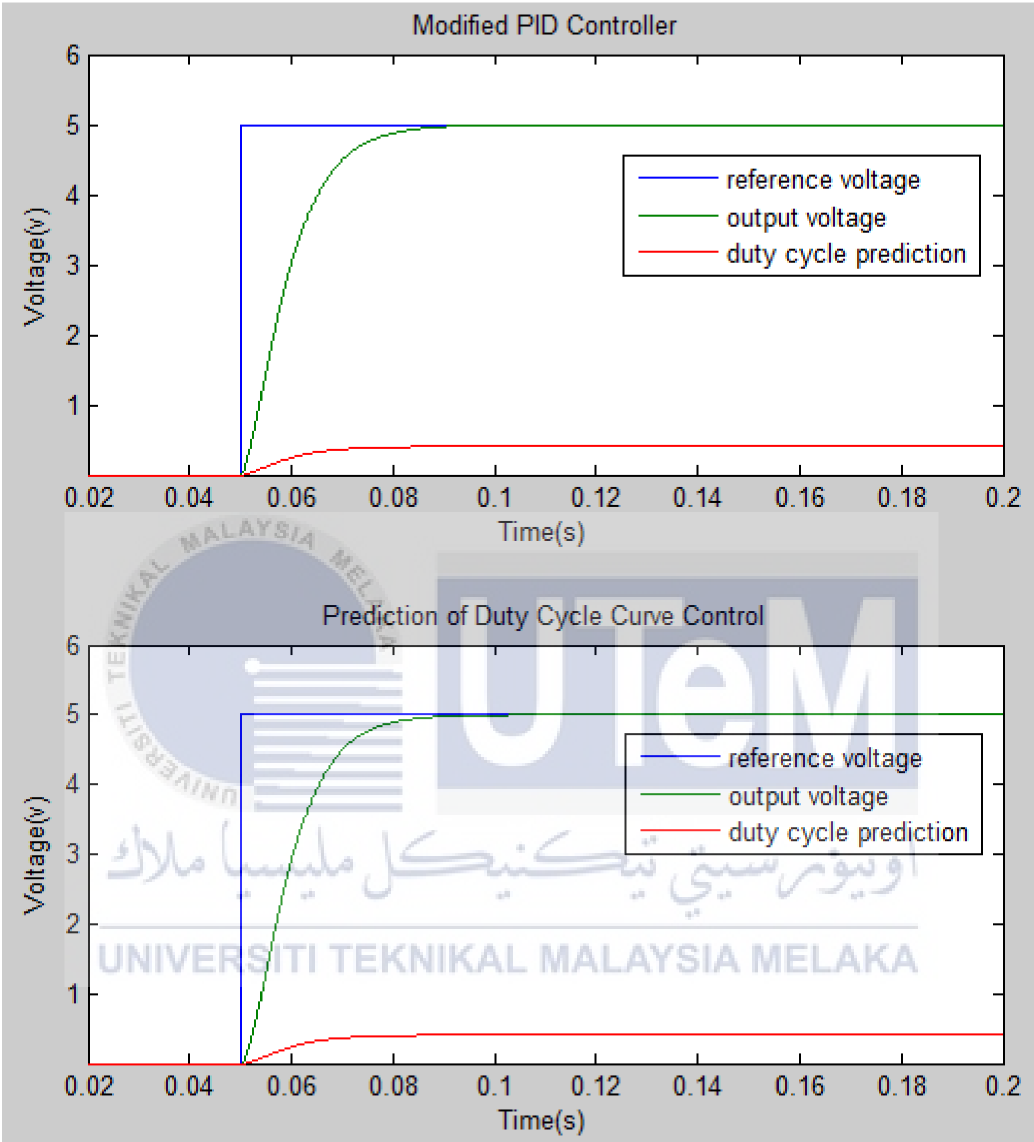


Figure 4.5: Step-up in The Reference (0-5V) at 0.05s

Figure 4.5 shows the comparison of output responses for prediction of duty cycle curve control with the modified PID controller. The similarity in both graphs proved that the proposed D curve prediction can be used as a new feedback control technique. It has achieved good transient response and zero steady-state.

4.2 Real Plant Method

4.2.1 System without Controller

There are three types of cases to be tested and shown in the below, which are change the reference voltage, change the load and change the input voltage.

Case 1: Change the reference voltage, $Vref$

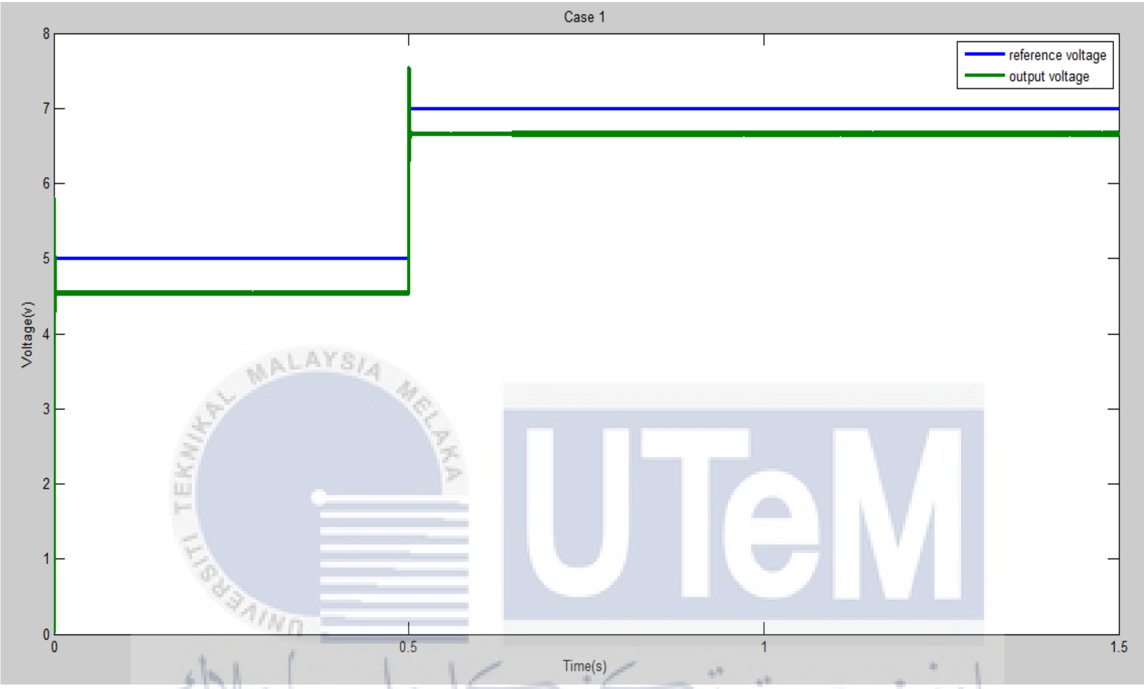


Figure 4.6: Reference Voltage Changed

i. Vo= 4.5V(first 0.5s), 6.7V(after 0.5s)

ii. Steady state error= 4% to 10%

iii. Settling time= 0.003s

Figure 4.6 shows the comparison between the reference voltage (blue line) and output voltage (green line). The transient response was not good and steady-state error occurred around 4% to 10%. The steady-state error was high. From the result, the graph showed it did not meet the condition of good transient response and zero steady state error. In conclusion, a controller needed to produce good transient response and zero steady state error.

Case 2: Change the load, R_L

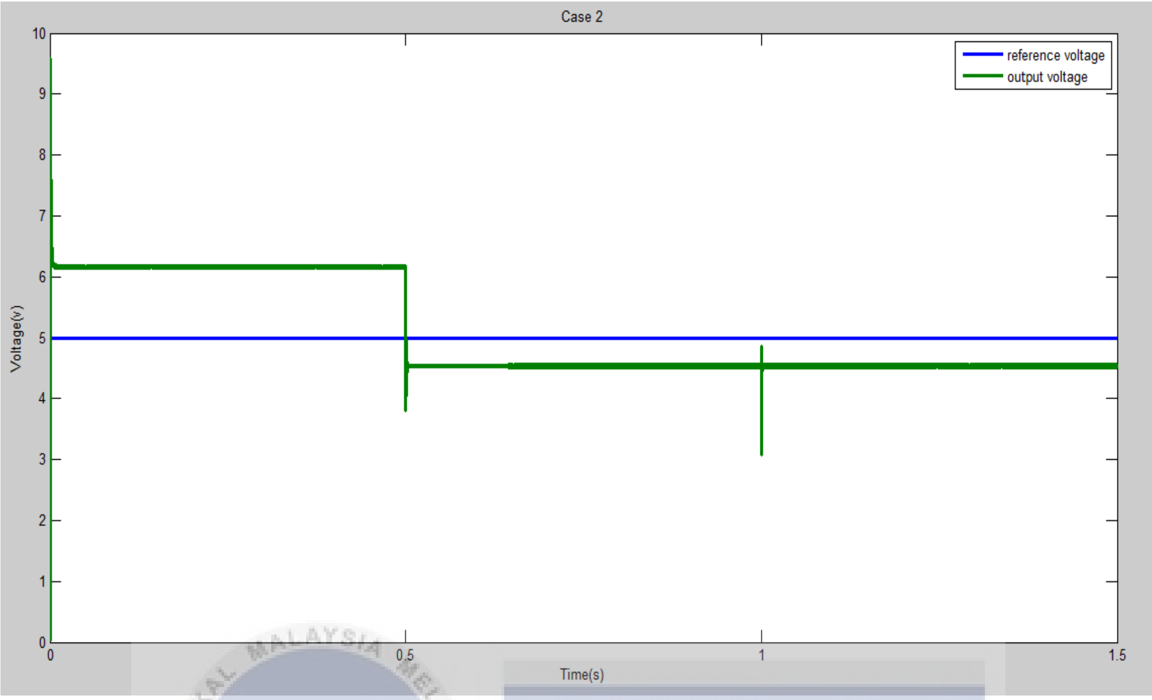


Figure 4.7: Load Changed

i. Vo= 6.2V(first 0.5s), 4.5V(after 0.5s)

ii. Steady state error= 10% to 24%

iii. Settling time=0.003s

Figure 4.7 shows the comparison between the reference voltage (blue line) and output voltage (green line). The transient response was not good and steady-state error occurred around 10% to 24%. The steady-state error was high. There are voltage drops occurred, however it did not follow the track of reference voltage. From the result, the graph showed it did not meet the condition of good transient response and zero steady state error. In conclusion, a controller needed to produce good transient response and zero steady state error.

Case 3: Change the input voltage, Vin

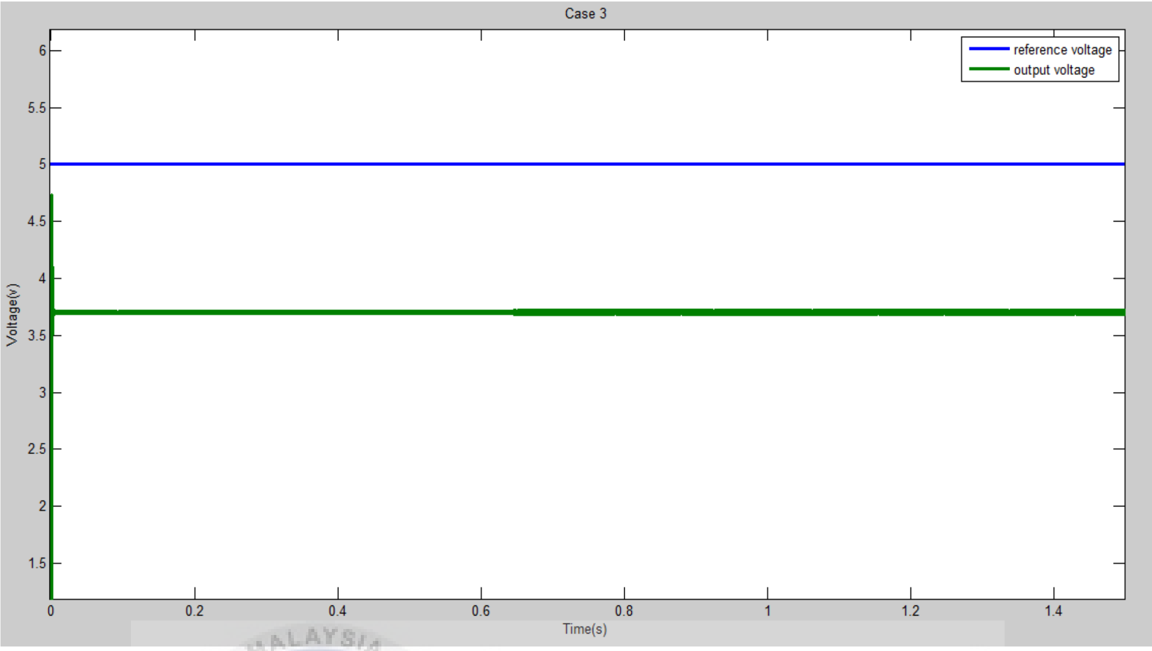


Figure 4.8: Input Voltage Changed

i. Vo= 3.72V
ii. Steady state error=25.6%
iii. Settling time=0.003s

Figure 4.8 shows the comparison between the reference voltage (blue line) and output voltage (green line). The transient response was not good and steady-state error occurred around 25.6%. The steady-state error was high. From the result, the graph showed it did not meet the condition of good transient response and zero steady state error. In conclusion, a controller needed to produce good transient response and zero steady state error.

4.2.2 System with Controller

There are three types of cases to be tested and shown in the below, which are change the reference voltage, change the load and change the input voltage.

Case 1: Change the reference voltage, $Vref$

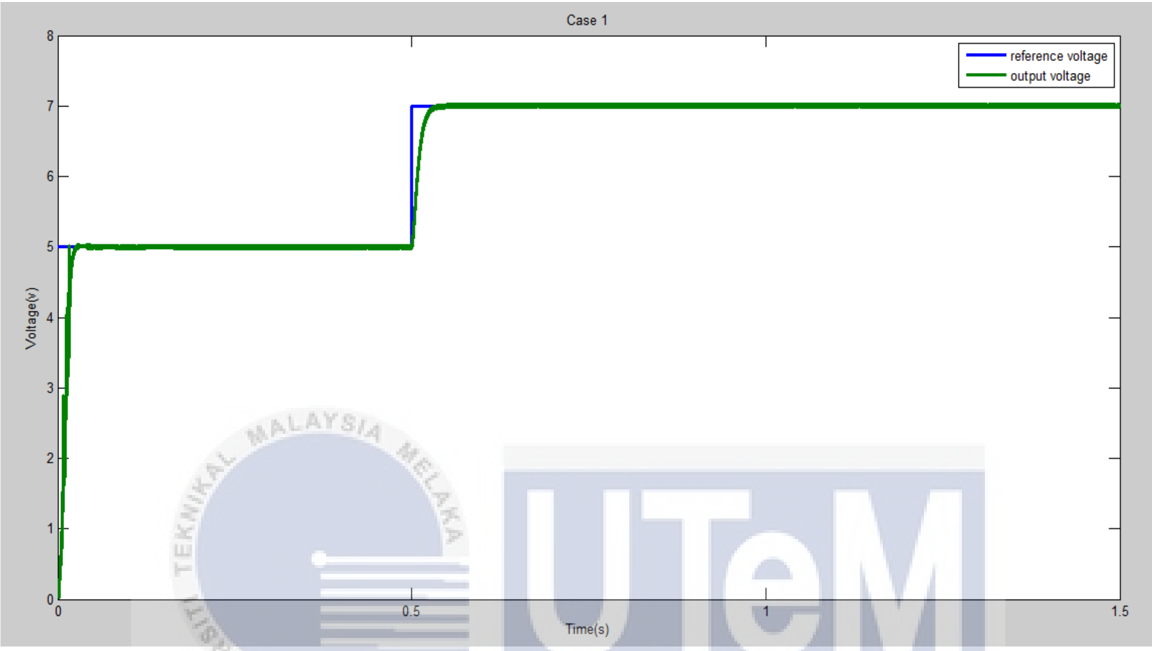


Figure 4.9: Reference Voltage Changed

i. Vo= 5V (first 0.5s), 7V (after 0.5s)

ii. Steady state error=0%

iii. Settling time= 0.02s

Figure 4.9 shows the comparison between the reference voltage (blue line) and output voltage (green line). The transient response was good and no steady-state error occurred. The steady-state error is 0%. From the result, the graph showed it met the condition of good transient response and zero steady state error. In conclusion, a modified PID controller can produce good transient response and zero steady state error.

Case 2: Change the load, R_L

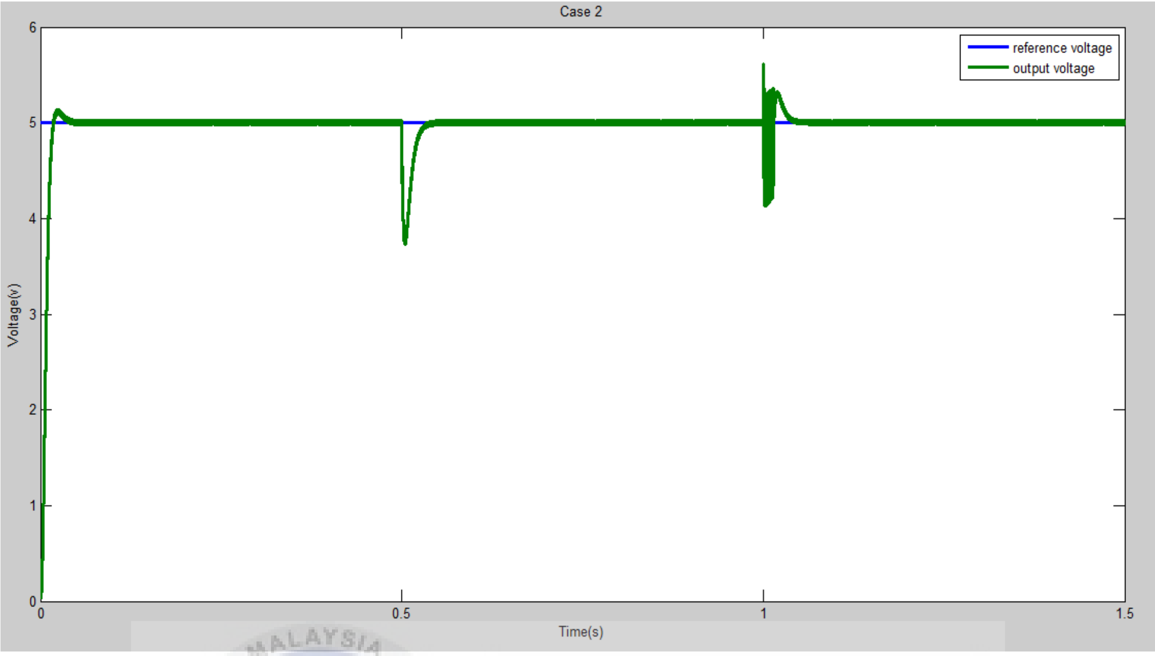


Figure 4.10: Load Changed

i. Vo= 5V

ii. Steady state error=0%

iii. Settling time=0.02s

Figure 4.10 shows the comparison between the reference voltage (blue line) and output voltage (green line). The transient response was good and no steady-state error occurred. The steady-state error is 0%. There were voltage drops to around 3.8V and 4V, however it followed back the track of reference voltage. From the result, the graph showed it met the condition of good transient response and zero steady state error. In conclusion, a modified PID controller can produce good transient response and zero steady state error.

Case 3: Change the input voltage, Vin

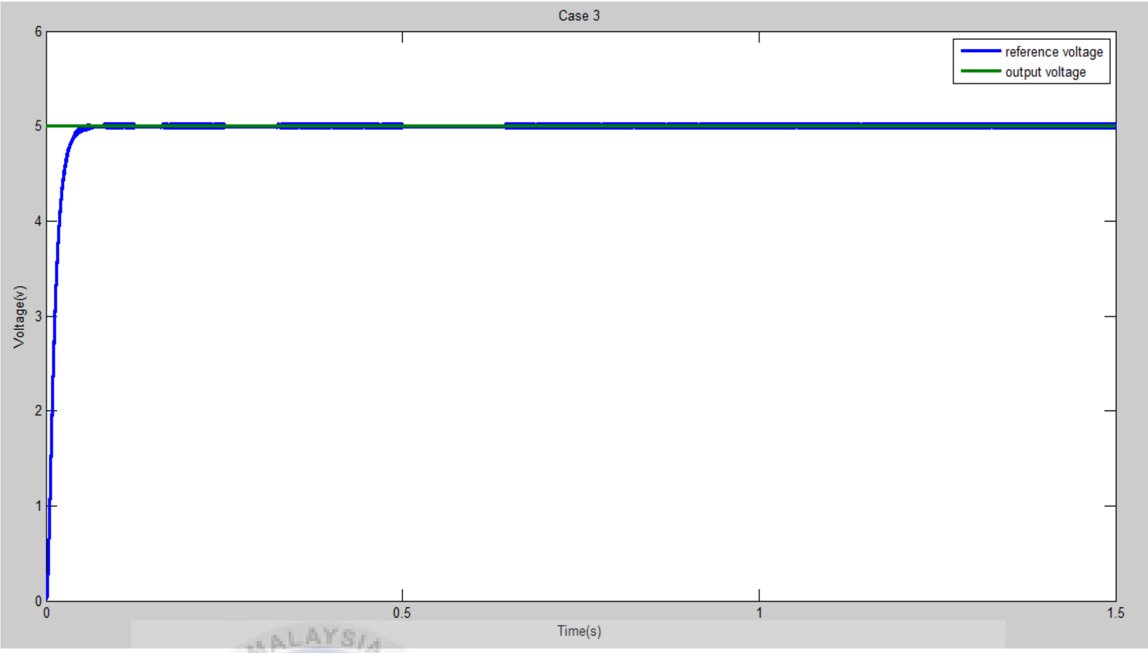


Figure 4.11: Input Voltage Changed

i. Vo= 5V

ii. Steady state error= 0%

iii. Settling time=0.02s

Figure 4.11 shows the comparison between the reference voltage (blue line) and output voltage (green line). The transient response was good and no steady-state error occurred. The steady-state error is 0%. From the result, the graph showed it met the condition of good transient response and zero steady state error. In conclusion, a modified PID controller can produce good transient response and zero steady state error.

4.2.3 Duty Cycle Prediction

The reference, output responses and the duty cycle prediction curve for both control systems are shown in Figure 4.12, for tests on step-up reference input, 0-5V at 0.05s.

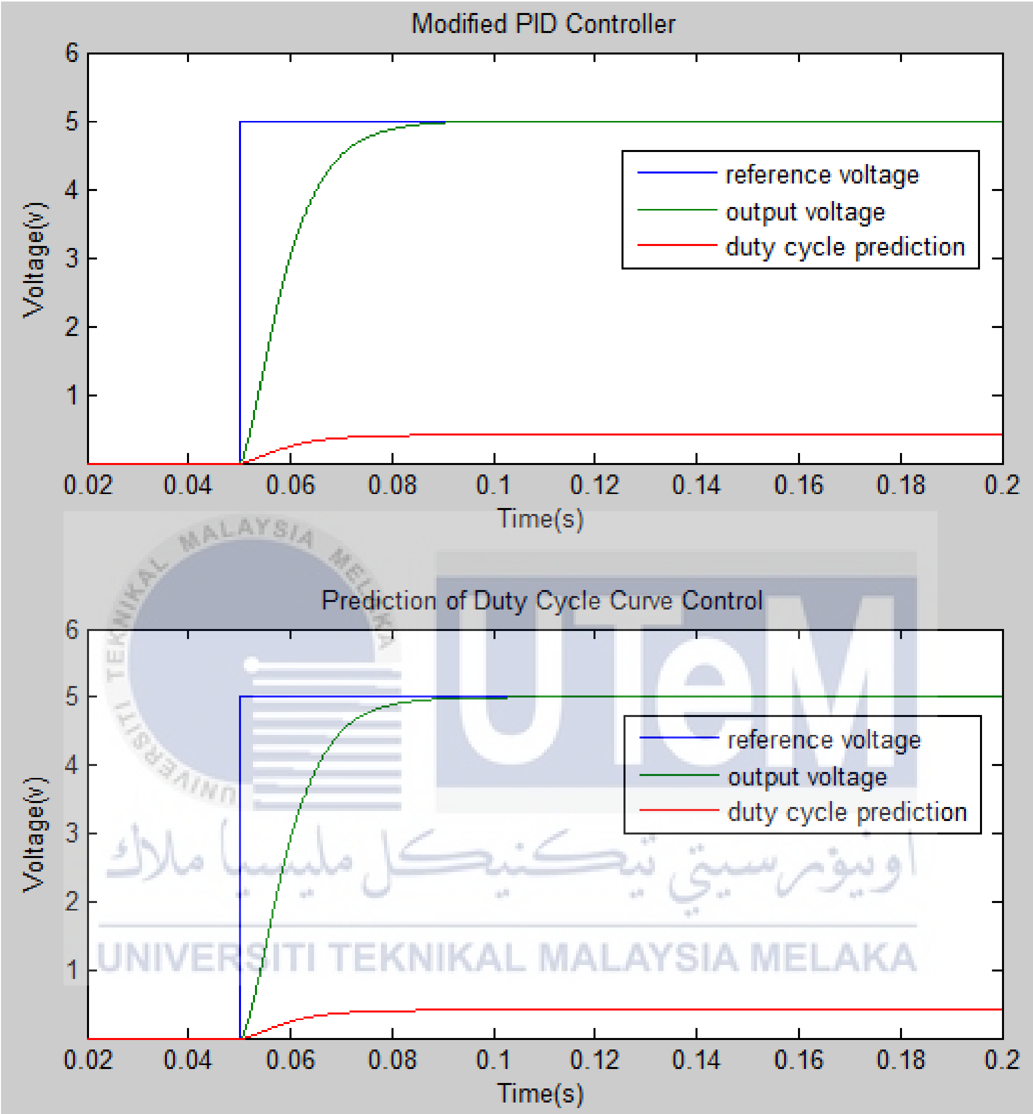


Figure 4.12: Step-up in The Reference (0-5V) at 0.05s

Figure 4.12 shows the comparison of output responses for prediction of duty cycle curve control with the modified PID controller. The similarity in both graphs proved that the proposed D curve prediction can be used as a new feedback control technique. It has been achieved good transient response and zero steady-state.

4.3 Limitation of the Modified PID Controller

There are limitation for the modified PID controller. It cannot response to bigger change in reference voltage, load and input voltage. There are three types of cases to be tested and shown in the below, which are changes in reference voltage, changes in load and changes in input voltage.

Case 1: Change the reference voltage, $Vref$

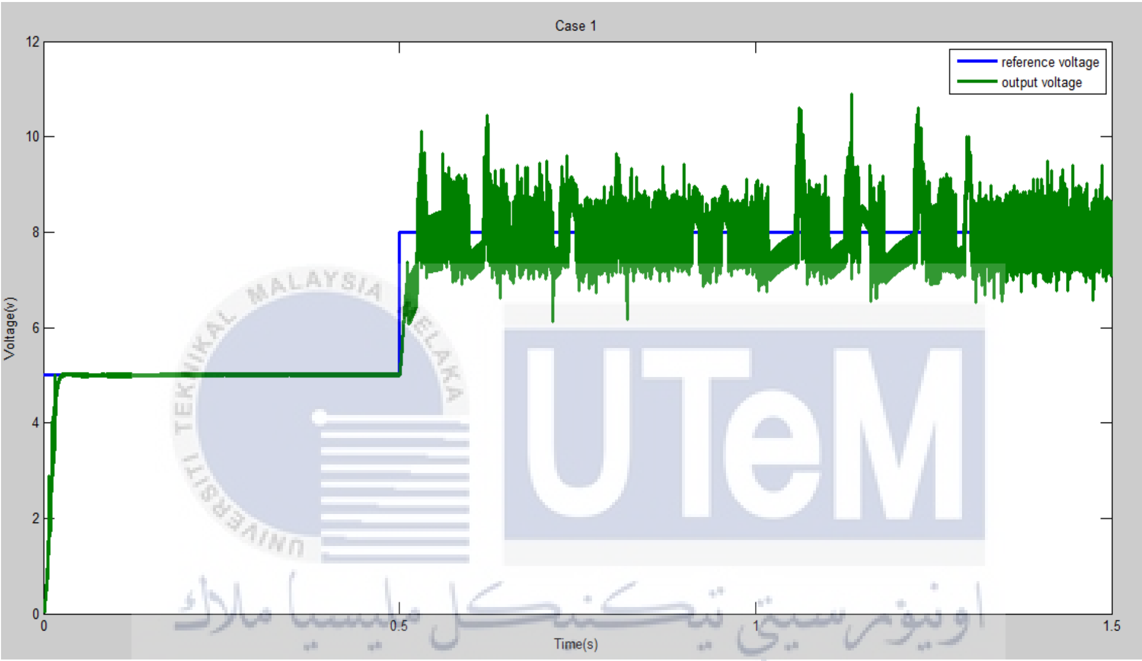


Figure 4.13: Reference Voltage Changed

Figure 4.13 shows the comparison between the reference voltage (blue line) and output voltage (green line). It showed that when the reference voltage changed to 8V, the manually constructed modified PID controller cannot function properly and showed the fluctuated graph after 0.5s. It meant the modified PID controller also has its own limitation too. It just can response to smaller changed in reference voltage. Therefore, a further research on modified PID controller should be carried out so that the controller is able to respond in bigger change in reference voltage.

Case 2: Change the load, R_L

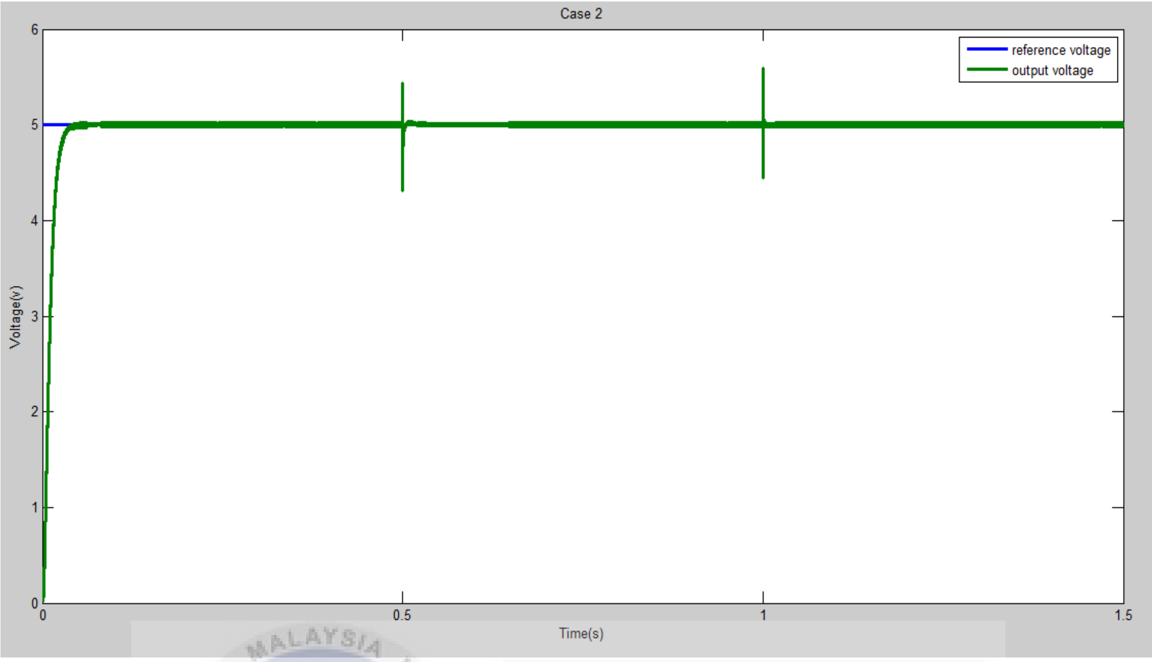


Figure 4.14: Load Changed

Figure 4.14 shows the comparison between the reference voltage (blue line) and output voltage (green line). It showed that when the load changed to 5.45Ω, the manually constructed modified showed it followed back the track of reference voltage, but the voltage drop was too little that can see from the graph. It meant the modified PID controller also has its own limitation too. It just can response to smaller changed in load. Therefore, a further research on modified PID controller should be carried out so that the controller is able to respond properly in bigger change in load.

Case 3: Change the input voltage, Vin

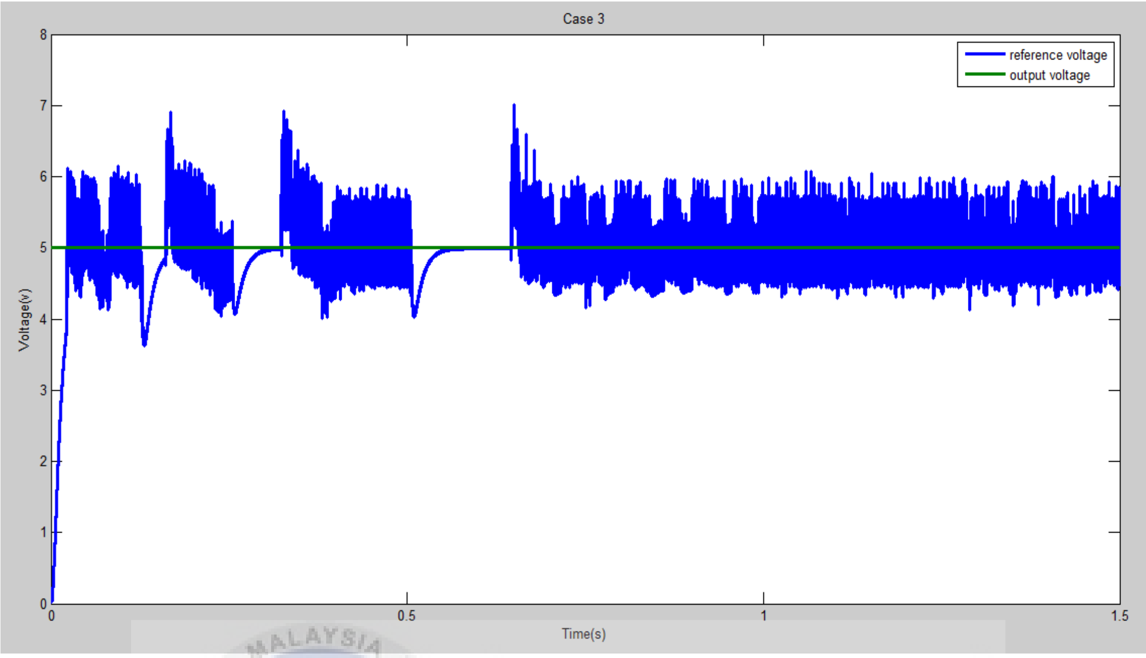


Figure 4.15: Input Voltage Changed

Figure 4.15 shows the comparison between the reference voltage (blue line) and output voltage (green line). It showed that when the input voltage changed to 8V, the manually constructed modified PID controller cannot function properly and the fluctuated along the graph. It meant the modified PID controller also has its own limitation too. It just can response to smaller changed in input voltage. Therefore, a further research on modified PID controller should be carried out so that the controller is able to respond in bigger change in input voltage.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

In conclusion, this project provided a brief overview and explanation of the operation of a DC-DC buck converter. DC-DC buck converter was chosen in this project because it is simple, low cost and high efficiency. Its function is to step down the input voltage to output voltage so that it can use in many areas and fields. It is able to convert a computer's main bulk supply voltage lower voltage that is needed by USB, RAM and CPU. The feedback needed in a system to produce good transient response and zero-steady-state error. Without feedback control strategy, the transient response of this system will not be good and steady-state error will occur. The PWM switching pattern and modified PID controller of DC-DC buck converter has been successfully developed by using MATLAB/Simulink.

From this research, there are two methods work on system with and without controller and for duty cycle prediction. Firstly was the system modeling method. Secondly was the real plant method.

For the first method, the modeling on DC-DC buck converter has been done to obtain the transfer function of plant system. The step response and root locus of the system with and without controller has been obtain by using coding in the MATLAB. Besides, the transient response and steady-state error by Duty Cycle Prediction Control Technique has been verified by using MATLAB/Simulink. The new control technique is simpler and more autonomous, for example physical implementation does not too much on the feedback-sensor information.

For the second method, a modified PID controller has been designed and constructed. The derivative time, derivative gain and gain value has been obtained by using the root locus technique. The algorithm used in the duty cycle prediction is based on the dominant poles and has been derived by using the partial fraction method. Eventually, the modified PID controller have been inserted into the system with controller and duty cycle prediction. For the system without and with controller, there are three cases have been tested which were changes in reference voltage, changes in load and changes in input voltage on system with and without controller. Since the input voltage set is 12V, yet all the result of three cases were under this voltage because this project is about DC-DC buck converter and it needed to step down the voltage from 12V to lower.

From the result, the transient response of system without controller produced oscillation and it took longer time to settle down. Therefore a feedback controller which was modified PID controller has been designed to ensure better performance which were good transient response and zero steady-state error. Three cases which were changes in reference voltage, load and input voltage have been tested by using modified PID controller and from the result it achieved good transient response and zero steady-state error. The proposed idea, Duty Cycle Prediction Control Technique has been used to compare the result with the modified PID controller. It was successfully perform the case change in reference voltage. It produced almost same performance with the modified PID controller which were good transient response and zero steady state. Therefore this technique can be used as the new feedback control technique. This technique is simpler and more autonomous. It do not produce set-point kick phenomenon too. It has solved the problem and its effectiveness was verified by using MATLAB.

Finally, there are some recommendations here. The modified PID controller also has its own limitation. It just can response to smaller changes in reference voltage, load and input voltage. If the changes in reference voltage, load and input voltage are big, it cannot perform well such as produced fluctuated graph, it did not follow the track on the graph and etc. On the other hand, there is also limited time to do research on Duty Cycle Prediction Control Technique too. Since this project is limited only for a year, so the load change and input voltage by using this technique do not have enough time to develop. Therefore, a further research on modified PID controller should be carried out so that the controller is able to respond in bigger change in reference voltage, load and input voltage while further research on Duty Cycle Prediction Control Technique need to be carried out to develop load change and input voltage.

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APPENDICES

Appendix A: Gantt chart of project for FYP 1

		Duration (weeks)													
no	activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Finalize FYP title and supervisor														
2	Gather important information based on title														
3	Briefing & online register title for PSM 1														
4	Research on project background														
5	Research on literature review														
6	Research on methodology of project														
7	Write report PSM 1														
8	Submission report PSM 1														
9	Presentation PSM 1														

Appendix B: Gantt chart of project for FYP 2

		Duration (weeks)													
no	activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Research on literature review	■	■	■	■	■	■	■	■	■	■	■	■	■	
2	Simulation of problem formulation	■	■	■	■	■									
3	Analysis of simulation					■	■	■	■						
4	Findings and conclusion								■	■	■				
5	Write report PSM 2					■	■	■	■	■	■	■	■	■	
6	Submission report PSM 2														■
7	Presentation PSM 2														■

Appendix C: Partial Fraction Expansion Method

To determine the output response in time domain through dominant poles location using Partial Fraction Expansion Method:

Poles: $-3.07x10^{-6}$, $-1.42x10^{-6}$

$$c(s) = \frac{1}{s(s + 3.07x10^{-6})(s + 1.42x10^{-6})}$$

$$c(s) = \frac{A}{s} + \frac{B}{s + 3.07x10^{-6}} + \frac{C}{s + 1.42x10^{-6}}$$

To solve the values A, B and C:

Using partial method, we get:

$$A = \frac{4.36x10^{-12}}{(s + 3.07x10^{-6})(S + 1.42x10^{-6})} \Big| s = 0 = 1$$

$$B = \frac{3.968x10^{-12}}{s(s + 1.42x10^{-6})} \Big| s = -3.07x10^{-6} = 0.8607$$

$$C = \frac{3.968x10^{-12}}{s(s + 3.07x10^{-6})} \Big| s = -1.42x10^{-6} = -1.8609$$

Taking inverse Laplace to obtain time responses, $c(t)$, to unit step input, we obtain:

$$c(s) = \frac{1}{s} + \frac{0.8607}{s + 3.07x10^{-6}} - \frac{1.8609}{s + 1.42x10^{-6}}$$

$$c(t) = 1 + 0.8607e^{-3.07x10^{-6}t} - 1.8609e^{-1.42x10^{-6}t}$$